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Editorial

Mechanical and Industrial Engineering deals with recent developments and practices adopted in various projects in different engineering disciplines and specializations - Rock Dredging; Concrete Technology; Grid Computing; Electric Propulsion & the Stationary Plasma Thruster; Turbo charging; Ultra filtration, Nan filtration & Reverse Osmosis; FACTS Devices; Sensors; Advanced Materials for Aircraft and Helicopters; Data Communication and Network Protocol; Satellite Communication Systems; Optoelectronic Devices; Wireless Communication; Applications of CFD Techniques in Aero-propulsive Characterization of Missiles; Hazardous Waste Management; Liquid Fueled SCRAMJET Combustors; Armor Materials and Designs; Heat Transfer in Nuclear Reactors; Defense Electronics Systems; World Class Manufacturing; Value Engineering & Engineering Ethics. Mechatronics is an interdisciplinary branch of mechanical engineering, electrical engineering and software engineering that is concerned with integrating electrical and mechanical engineering to create hybrid systems. In this way, machines can be automated through the use of electric motors, servo-mechanisms, and other electrical systems in conjunction with special software. A common example of a Mechatronics system is a CD-ROM drive. Mechanical systems open and close the drive, spin the CD and move the laser, while an optical system reads the data on the CD and converts it to bits. Integrated software controls the process and communicates the contents of the CD to the computer.

Robotics is the application of Mechatronics to create robots, which are often used in industry to perform tasks that are dangerous, unpleasant, or repetitive. These robots may be of any shape and size, but all are preprogrammed and interact physically with the world. To create a robot, an engineer typically employs kinematics (to determine the robot's range of motion) and mechanics (to determine the stresses within the robot). Robots are used extensively in industrial engineering. They allow businesses to save money on labor, perform tasks that are either too dangerous or too precise for humans to perform them economically, and to ensure better quality. Many companies employ assembly lines of robots, especially in Automotive Industries and some factories are so robotized that they can run by themselves. Outside the factory, robots have been employed in bomb disposal, space exploration, and many other fields. Robots are also sold for various residential applications, from recreation to domestic applications.

The field of mechanical engineering can be thought of as a collection of many mechanical engineering science disciplines. Several of these sub disciplines which are typically taught at the undergraduate level are listed below, with a brief explanation and the most common application of each. Some of these sub disciplines are unique to mechanical engineering, while others are a combination of mechanical engineering and one or more other disciplines. Researchers are working on applying their wireless and mobile research to transportation, health care, education, collaboration and environmental sustainability. Projects already underway include safe and efficient road transportation, autonomous driving, wireless medical implants, mobile video delivery, multiparty wireless videoconferencing and energy harvesting.

The Conference sometimes is conducted in collaboration with other institutions. IOAJ encourage and invite proposals from institutes within India to join hands to promote research in various areas of discipline. These conferences have not only promoted the international exchange and cooperation, but have also won favorable comments from national and international participants, thus enabled IOAJ to reach out to a global network within three years time. The conference is first of its kind and gets granted with lot of blessings.

The conference designed to stimulate the young minds including Research Scholars, Academicians, and Practitioners to contribute their ideas, thoughts and nobility in these disciplines of Engineering. IOAJ received a great response from all parts of country and abroad for the presentation and publication in the proceeding of the conference.

I sincerely thank all the authors for their invaluable contribution to this conference. I am indebted towards the reviewers and Board of Editors for their generous gifts of time, energy and effort. It's my pleasure to welcome all the participants, delegates and organizer to this international conference on behalf of IOAJ family members.

Convener:

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A REVIEW ON PRECISION MACHINING OF GLASS

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Abstract- In this paper an attempt has been made to review the literature on different ways and methods of machining on glass. Various conventional techniques such as milling, drilling, polishing have been studied. Also different modern techniques using Laser and Electro chemical discharge machining have been studied. There are also the combination of the conventional and the modern techniques which have been successfully applied and a study of which has been done in the paper. Many of the above techniques are being used successfully in many of the industries to perform machining operation on glass.

1. INTRODUCTION

Ultra-precision machining technology has been developed over recent years for the manufacture of cost-effective and quality-assured precision parts for several industrial applications such as lasers, optics, semiconductors, aerospace and automobile applications. Precision manufacturing deals with the realisation of products with high shape accuracy and surface quality. The accuracy may be at the nanometric level. Several machining techniques can be mentioned here like diamond turning, grinding, lapping, polishing, honing, ion and electron-beam machining, laser machining etc. Efficient overviews of the processes are given in Refs. [1–3]. Ultra-precision machining technology has been highly developed since the 1980s mainly because of its high accuracy and high productivity in the manufacturing of optical, mechanical and electronic components for industrial use. For many advanced technology systems, higher fabrication precision is complicated by the use of brittle materials.

Glass is a homogeneous material with amorphous crystal structure that is produced through the rapid cooling of its molten state below the glass transition temperature. Glass exhibits many excellent mechanical and physical properties such as high hardness, transparency, good corrosion and chemical resistance, and high electrical resistivity. It is widely used in automotive, communications, optics, electronics, architectural, and biomedical industries. 3D microstructures in glass materials are required for optical waveguides, micro fluidic chips etc. It would be ideal to fabricate some glass devices through mechanical micromachining for some rapid prototyping applications of glass-based devices, but the brittle nature of glass makes machining difficult. The machined surface is usually fractured and requires additional finishing processes that are costly and time consuming. Here we study the latest developments in the machining processes that lead to a better finish and higher productivity.

2. REVIEW ON MACHINING USING ABRASIVES

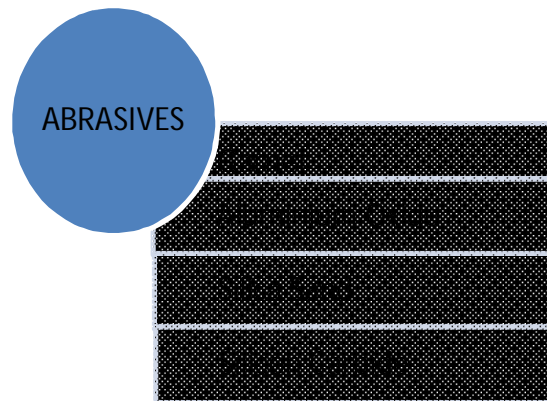


Table 1. Types of abrasives

The use of abrasives for the process of machining has played a major role in the machining of glass. Different forms of machining using abrasives have been performed on glass and with successful results. Different abrasives used are Garnet, Aluminium oxide, silica sand, silicon carbide etc. A.A Khan et al. studied the performance of different abrasives during abrasive water jet machining of glass. Garnet abrasives produce the smallest width of cut followed by aluminium oxide and silicon carbide. Ninety percent of Abrasive water jet machining is done using garnet. Cutting parameters are abrasive jet pressure, standoff distance (SOD) of the nozzle from target, work feed rate, abrasive mass flow rate. They concluded that the taper of cut increase with an increase in SOD. Garnet produced a larger taper of cut. Taper of cut increases with increase in feed rate and decreases with increasing pressure. P.S Sreejith et al. have described about Free abrasive machining (FAM). FAM is a machining process that utilises abrasives such as diamond, silicon carbide, boron carbide and aluminium oxide for stock removal and finishing. The abrasive in FAM is usually mixed with a liquid to form a slurry. This slurry is placed

between a hard(60–62 Rc) rotating wheel, called the lapping block, and the workpiece. The lapping block is usually made of hardened steel. The schematic figure is shown.

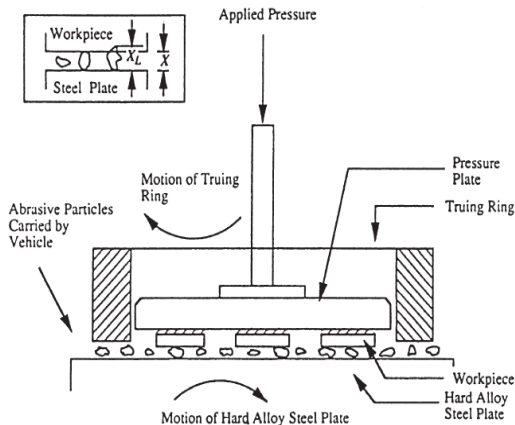


Fig 1. Free abrasive machining

Under certain controlled conditions, it is possible to machine brittle materials like ceramics using single- or multi-point diamond tools so that material is removed by plastic flow, leaving a crack-free surface. This process is called ductile regime machining. Ductile regime machining follows from the fact that all materials will deform plastically if the scale of deformation is very small.

Fuqian Yang et al. used the principle of FAM in slicing brittle materials such as quartz and glass with a wire saw. Wiresaw has emerged as a leading technology in wafer preparation for microelectronics fabrication.

Osama Horiuchi et al. described Nano abrasion machining as follows. In abrasive machining if the collision energy is low and the collision angle is shallow the abrasion rate may reduce down to a few nanometres per minute and ductile mode abrasion with a few nanometres surface roughness may occur for brittle materials. Nano-abrasion machining was applied to corrective figuring of optical glass of BK7. The flatness was improved from $PV = 151$ to 29 nm. The setup is shown below.

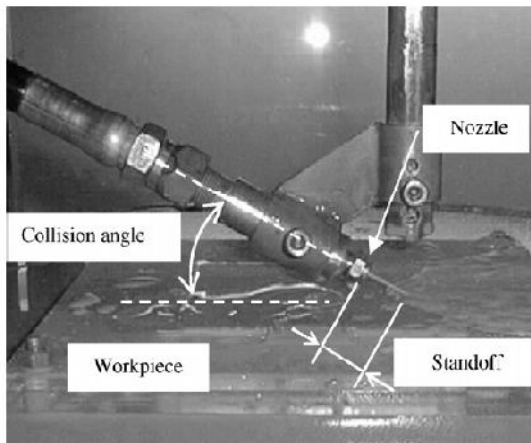


Fig 2. Nano abrasion machining

2. GRINDIND AND POLISHING METHODS



Table 2. Types of grinding and polishing

Different forms of grinding and polishing methods are used for the purpose of obtaining a smooth finish in glass. D.J Stephenson et al, made a study on Electrolytic In process Dressing ultra precision grinding of optical glass. ELID was used to alleviate wheel loading for fine grit size metal bond wheels. ELID is an electrochemical technique that continuously dresses a metal bond wheel through in situ electrolysis [3–7]. Electrolysis chemically modifies the grinding wheel surface and the modified layer of the grinding wheel is removed in the grinding process to provide the necessary grit protrusion and chip storage space.

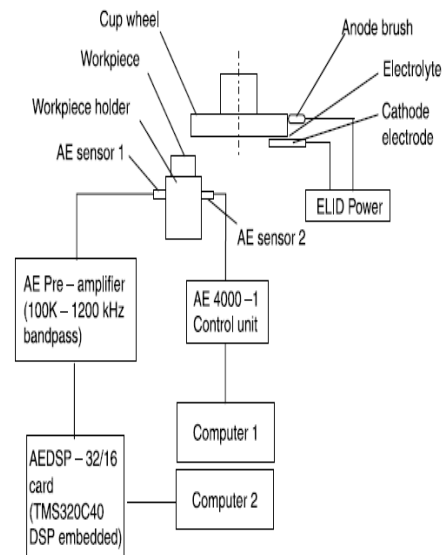


Fig 3. ELID grinding

The ELID system used stainless steel as the cathode electrode, covering 1/6 of the wheel surfaces with a 220 mm dressing gap. A synthetic water soluble grinding fluid CEM, Fuji Die, Japan, was applied as coolant and electrolyte.

V Sinhoff studied the generative precision grinding of optical glass. The generative grinding principle, is highly flexible since the diamond-coated cup wheels can be used to machine a variety of spherical radii. In contrast, the reproductive pellet tools, which are used in conventional precision grinding operations, are limited to one single geometry.

The traditional polishing method to obtain super smooth surfaces is abrasive polishing. Wu Xiaosheng et al, proposed a new kind of polishing method called non-abrasive polishing (NAP). The polishing wheel of NAP is made of ice that is frozen deionised water, so there is no abrasive in the polishing wheel. Compared with traditional polishing methods, NAP can obtain Angstrom-order surface roughness values free from microscratches and subsurface cracks. The best surface roughness, $R_a=0.48$ nm, of K9 glass is obtained using NAP.

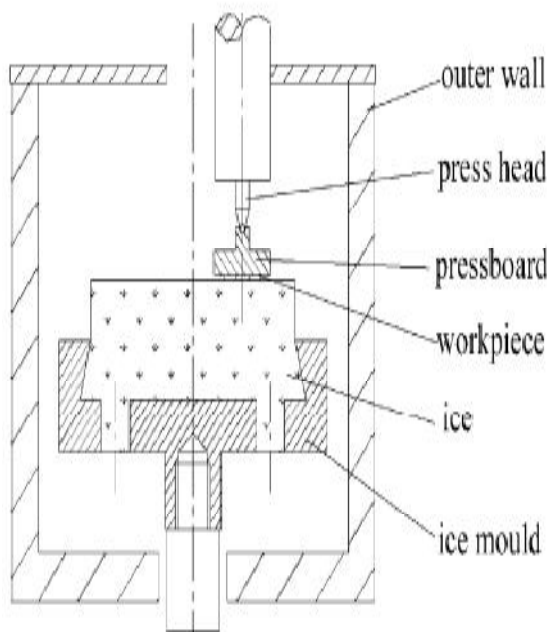


Fig 4. Non Abrasive Polishing

Yoshiharu Namba et al, proposed a method of Ultra precision float polishing of optical materials. The polishing fluid was a mixture of pure water and 3wt% SiO₂ powder, and was controlled within a temperature range of 0.01K. Polishing pressure was only applied by the weight of the sample and sample holder.

D Golini et al proposed a new method of polishing using Magneto Rheological Fluid(MRF). One composition, which consists of cerium oxide in an aqueous suspension of magnetic carbonyl iron (CI) powder, has been found appropriate for almost all soft and hard optical glasses and low-expansion glass-ceramics. The magnetic carbonyl iron particles may be thought of as a form of variable compliance lap that supports the nonmagnetic polishing abrasives. Lap stiffness may be increased or decreased by adjusting the CI concentration and/or

the magnetic field strength. The experimental set up is shown below.

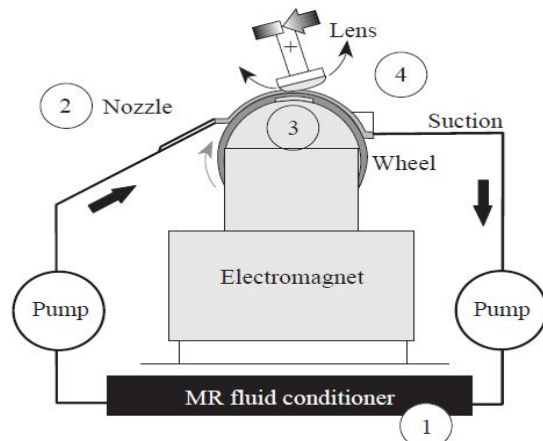


Fig 5. MRF polishing

3. LASER BASED METHODS FOR THE MACHINING OF GLASS

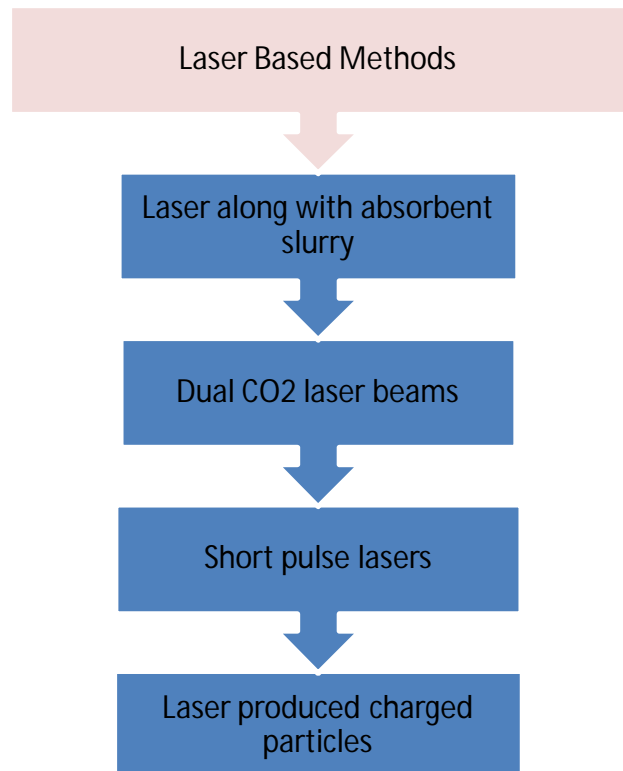


Table 3. Laser based methods

Different kinds of laser based methods have been developed for the machining of glass and are being widely used. Some of the common and latest methods have been reviewed here. M. Mitsuishi et al, investigated a method for machining a 3D micro channel in silica glass using a UV nanosecond pulsed laser and an absorbent slurry. Etching generates undesirable cracks. Furthermore, a femtosecond laser may not be appropriate in many applications because of its high cost. Therefore, in the paper, the authors have investigated a method for machining inside of a

glass material using a popular and inexpensive UV nanosecond laser. In the system, absorbent slurry, an inorganic Nano powder is used.

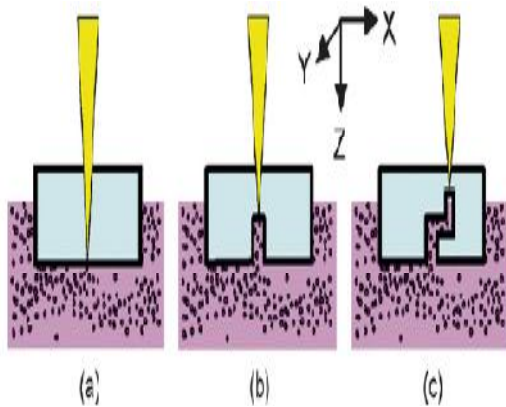


Fig 6. Machining using Slurry

A groove with a length of 500µm was machined by the liner motion of the laser. The groove depth increased as the absorbent concentration and the pulse energy increased.

Junke Jiao et al, did a study on machining of glass by dual CO2 laser beams. In order to reduce the possibility of fracture in the process of cutting glass by lasers, the thermal stress has to be less than the critical rupture strength. Off focus CO2 laser beam is used to pre heat glass sample to reduce the thermal gradients and focused CO2 laser beam was used to machine glass. Thermal stress reduced from 61.2Mpa to 38.9Mpa.

S.Nikumb et al, proposed precision glass machining by short pulse lasers. Short pulse solid state lasers with pulse duration in the nanosecond to femtosecond range were used to process different types of glass materials. Due to the presence of thermal effects the spatial resolution available from conventional wider pulses lasers operating at visible and infrared wavelengths of the spectrum is limited. Two ways to overcome this limitation, one way is to use UV lasers wavelength that can be focused down to smaller spot size and thereby reduce the extent of thermal damage around machined edges. The other approach is to use ultra fast lasers with much shorter pulse durations like picoseconds or femtosecond regimes. The laser used in this work includes an NdYag laser. They carried out laser micromachining of glass using ns lasers and femtosecond laser drilling of micro hole arrays.

Chengde Li et al reported ultra fine machining of glass substrates using charged particles from laser produced metal plasma. In this method, initially, the laser beam produces plasma from a metal target. The charged particles in the corona region of the plasma are used to etch

the glass substrate. It has been shown that high-quality, ultra-fine surface machining of glass materials can be achieved with this process. Brass and bronze foils with a thickness of 0.076mm were

used as target materials. The separation between the glass and metal target is 30µm.

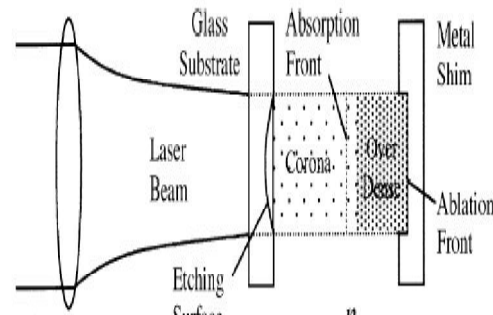


Fig 7. Machining using plasma

4. ULTRASONIC MACHINING TECHNIQUES

In the process of the Ultrasonic machining (USM), materials are removed by micro chipping or erosion with the abrasive particles. The tip of the tool vibrates at low amplitude (2–50 µm) and high frequency (20 kHz), which transmits a high velocity to the fine abrasive grains between the tool and the surface of the work piece. The chemical composition of the work piece, the size of the abrasive particles and the static load affect the characteristics of ultrasonic machining. J.P Choi et al developed a novel chemical assisted ultrasonic machining (CUSM) method is introduced to overcome the disadvantages of USM. To get the chemical effect a low concentration of hydrofluoric acid was added to the abrasive slurry. As shown in the figure the transmitted energy increases and results in deep median cracks and therefore the crater size is reduced and the material removal is increased.

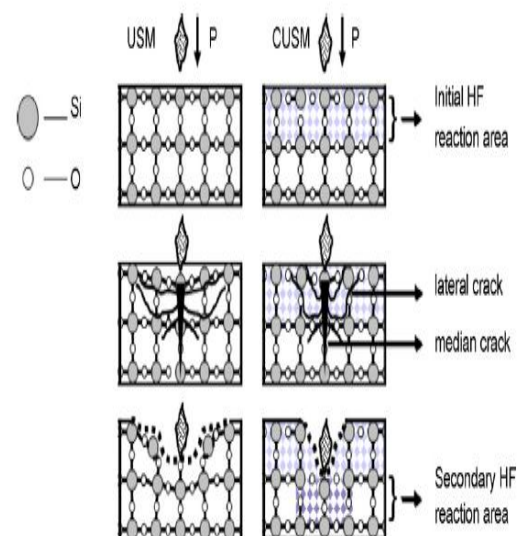


Fig 8. Chemical Assisted Ultrasonic machining

When the CUSM is used, the machining rate enhanced about 30-35% comparing to the conventional USM. The surface roughness was improved as well. 3-5% HF solution is suitable for the CUSM process.

5. ELECTROCHEMICAL DISCHARGE MACHINING AND DIFFERENT VARIANTS

Electro Chemical Discharge Machining (ECDM) is an emerging hybrid machining process used in precision machining of hard and brittle non-conducting materials. Much of the work in ECDM has been concentrated on glass (pyrex and borosilicate), which has useful properties and applications in industrial, defence, medical and electronic industries.

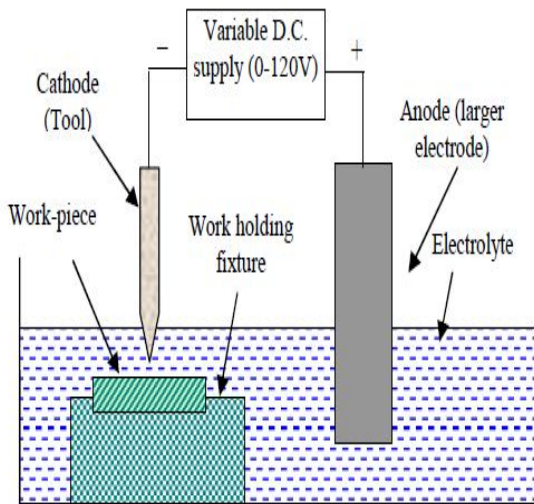


Fig 9. ECDM process

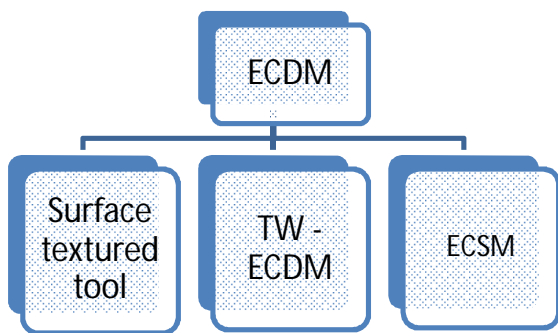


Table 4. Types of ECDM

The tool used was made of stainless steel(diameter 0.7 mm). The auto feed motions of the machine were used for making the micro-channels. The obtained dimensions were in the range of length 10 to 15 mms,width 0.8 to 1mm and depth 0.1 to 0.2 mm. W.Y Peng et al did a study on electrochemical discharge machining technology for slicing non conductive brittle materials. Travelling wire

electrochemical discharge machining(TW-ECDM) a newly developed technology is used to slice the small size (10-30mm diameter) optical glass and quartz bar.

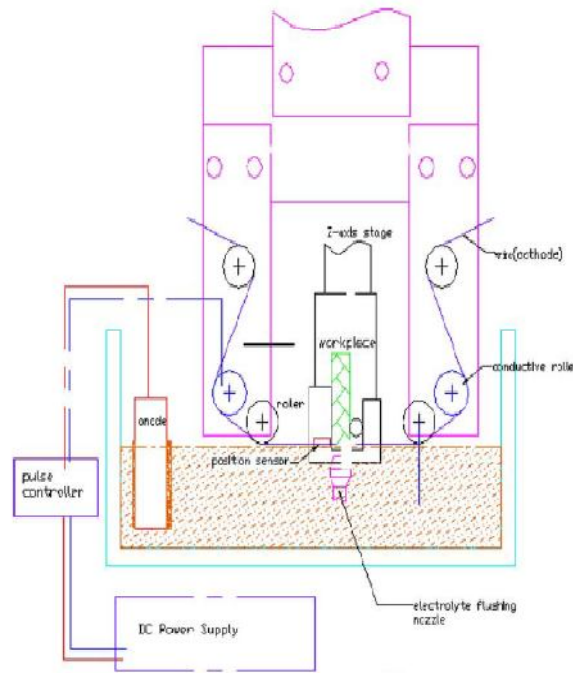


Fig 10. TW ECDM

Copper wires can evoke more sparks which result from lower surface contact resistance and it has stable and ideal performance if the wire is no larger than 40mm. However the stainless steel wire can sustain higher voltage and stronger erosive destruction. KOH is used as the electrolyte.

Min Seop Han et al developed the micro electro chemical discharge cutting of glass using a surface textured tool. A surface textured tool is proposed to reduce the working voltage by enhancing the electric field intensity around the tool surface.

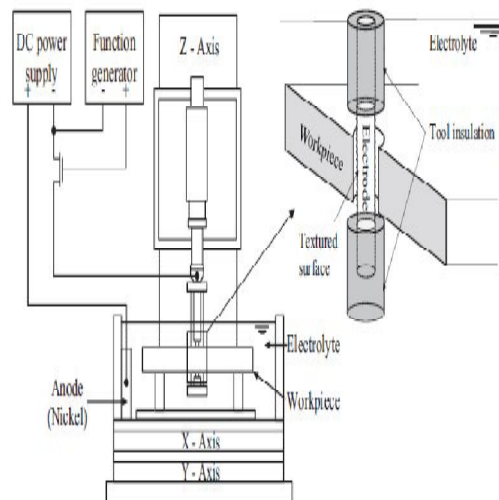


Fig 11. ECDM using surface textured tool

Value of V_{min} was reduced to 10VDC with an enhanced spark frequency of 1.5kHz. The surface quality was noticeably improved and the resulting Ra was as low as 0.3 μ m. Surface textured tool with a Ra of 1.5 μ m exhibited an enhanced discharge frequency compared to the smooth tool with Ra of 0.1 μ m.

V.K Jain et al developed a new method called the Electrochemical Spark abrasive drilling (ECSAD). Electrochemical spark machining (ECSM) process is a potential process for machining these materials. However, ECSM has its own inherent limitations. So far, only ordinary cutting tools have been used during ECSM by previous researchers, but the results obtained are not as good as anticipated. Electrochemical spark abrasive drilling (ECSAD) experiments have been conducted using abrasive cutting tools, with a view to enhance the capabilities of the process. Use of an abrasive cutting tool, when compared to a conventional cutting tool, has been found to improve the process performance, viz. enhanced material removal and increased machined depth. Hydrogen bubbles are evolved at the cathode and material removal is accomplished by establishing sparks across these bubbles in the vicinity of the workpiece immersed in electrolyte.

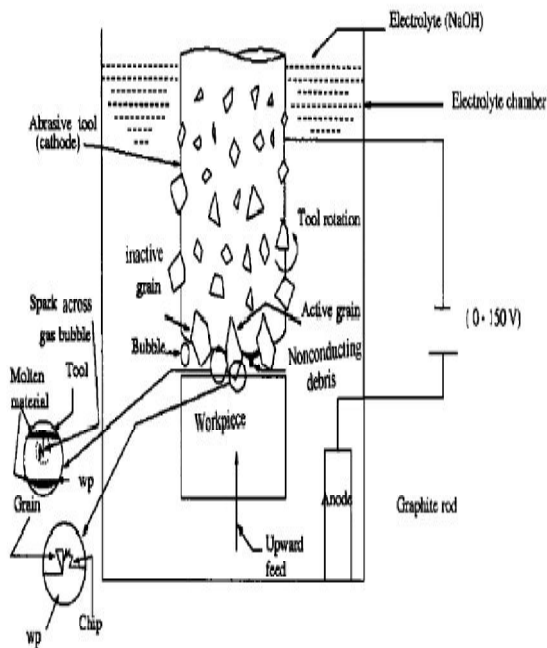


Fig 12. Electrochemical Spark abrasive drilling

This hybrid process combines electrochemical spark drilling with abrasive machining using a rotating tool impregnated with abrasive particles. The major limitation is low penetration depth. As the supply voltage increase the material removed also increases, as the electrolyte temperature increases material removal increases.

B.H Yan et al developed a method wherein a circular micro tool was produced using the micro electrical discharge machining process and this tool was then

used to drill a hole in glass using the micro ultrasonic vibration process.

The machining processes were divided into two main parts. First, the tungsten carbide rod was fashioned into a micro-tool using a copper plate as electrode in the EDM step. This tool was then used with the MUSM procedure to drill a micro-hole in the borosilicate glass. To produce high stress concentration in the workpiece during MUSM, the front end of the micro-tool was reduced in diameter to 20 μ m and length 0.2 mm. Highly accurate micro-holes with diameters of about 150 μ m and depth of 500 μ m were manufactured via the MUSM method. The experiments revealed that the Diameter variations between entrances and exits (DVEE) are influenced by the slurry concentration, ultrasonic vibration amplitude or rotational speed of the micro-tool.

Jana D AbouZiki et al demonstrated that electrochemical discharge machining can be used as a tool to change the surface texture of glass micro channels. For low electrolyte concentration feathery like patterns are formed while for high electrolyte concentration spongy like porous texture results. It was shown that the channels machined at low speed (5 mm/s) had a uniform surface texture and flat walls as compared to channels machined at higher speed (10 mm/s and 20 mm/s). With higher tool speeds, the channels become shallower. Hence, by tuning the electrolyte viscosity and the tool-electrode speed channels with different patterns and sharp edges can be obtained.

6. REVIEW ON APPLICATION OF DIAMOND IN GLASS FABRICATION

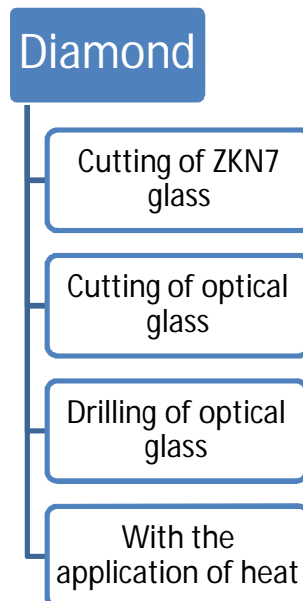


Table 5. Diamond based applications

J. Brand et al studied the application of diamond like carbon ((DLC) coatings on steel tools in the production of precision glass components. Glass forming is performed with hot glass at temperatures near the glass softening point at approximately 800 degree C. Unfortunately in this temperature range there is a good wetting of the glass melt on the steel surface of the forming tools. The wetting behaviour of the glass not only leads to damages on the formed glass component but also attacks the forming tool surface. As a consequence, separating agents are indispensable. Apparently there are several drawbacks: (1) the agent has to be applied by hand. (2) It contains solvents that are harmful to health and environment. (3) It leads to contamination of the glass surface through embedding of small particles. Replacing the separating agent therefore is of great ecological and economical interest. Hence the DLC coatings can be used to avoid the above said drawbacks and induce a smooth finish. Coatings show excellent wear resistance and have very low adhesion tendency towards 800 degree C hot glass.

F.Z Fang et al studied the ultra precision cutting of ZKN7 glass using a diamond tool. The cutting experiments were carried out on an ultra-precision turning machine with feedback resolution of 8nm. The work material is ZKN7, which is a silicate glass with a Knoop Hardness of 530 kg/mm² and a high softening point of 721 degrees Celsius. During the turning of ZKN7 a number of cutting conditions were tried to get the best surface. A single crystal diamond tool with a rake angle of 0 degree with a cutting edge radius 110 nm and a nose radius 1.00mm (the contour waviness less than 0.25µm) was used to turn the optical glass.

It has been shown that, subject to holding the undeformed chip thickness to sub-micrometer, mirror finishes have been achieved in ductile mode cutting after optimizing the cutting parameters, where the surface roughness value is Ra = 14.5nm. The cutting force of ZKN7 glass is around 1 N during ductile mode cutting, but the shear stress in both the work material and cutter increases sharply and becomes very large resulting in rapid tool wear when undeformed chip thickness becomes less than 1 µm.

In order to diamond turn optical glass it is necessary to determine the transition point from brittle mode to ductile mode. In machining glasses, a negative rake angle face is necessary to produce sufficient hydrostatic compressive stress in the cutting zone. This compressive stress makes the material transit from the brittle regime to a ductile regime. In conventional machining, the cutting edge radius of carbide tools can be considered to be sharp as the undeformed chip thickness is substantially larger than the radius value. When the cutting edge radius is larger than the undeformed chip thickness in ultra-precision machining of brittle materials, even though the actual rake angle is 0 degree, the effective rake angle γ_{eff} is a large negative value. However, an

extreme negative rake with large edge radius has a negative effective rake that could be much higher, creating more ploughing and sliding instead of chip formation.

Due to serious problems with tool life, extensive studies have been conducted. One approach to prolonging tool life is to apply ultrasonic vibration to the diamond cutting tool. The idea is that with vibration during cutting, the lubricant can easily penetrate the cutting zone. Also, the chatter contact time between the cutting tool and work material improves the tool life. In addition to increasing the tool life, another advantage of the use of ultrasonic vibration assisted cutting is that the critical depth of cut can be increased.

With increases in temperature, glasses soften and the materials become less brittle. Brehmet *al* (1979) applied a slit-burner and a point burner as heaters to elevate the workpiece temperature as shown in figure 13. The point burner directed just above the tool tip. The heat output is continuously adjustable. The burners heat the workpiece up to the glass removal condition beyond the glass transition temperature. The point burner at the same time acts locally in improving the surface finish without geometrically disturbing the bulk of the glass. However at elevated temperatures diamond turns into graphite.

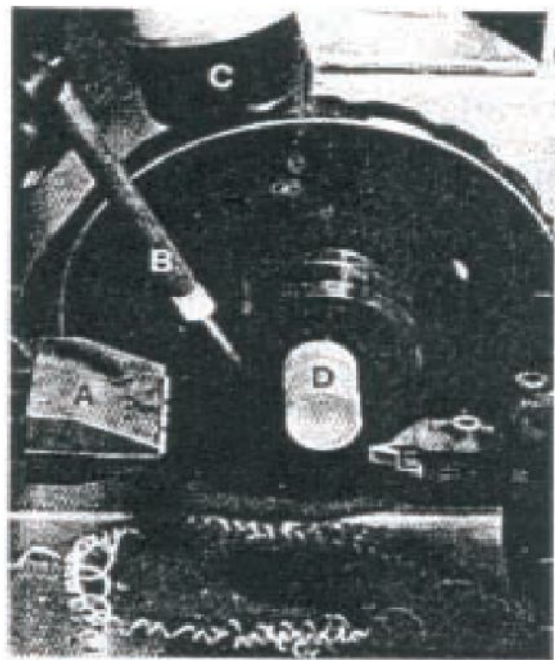


Fig 13. Effect of heat while machining

Hafnium Nitride was found to be by far the best tool material for this application due to its properties maintained at high temperature.

7. REVIEW ON SOME OF THE OTHER METHODS

It has been found that glass can be machined in a ductile regime under certain controlled cutting

configurations. However, favourable ductile regime machining instead of brittle regime machining in micro milling of brittle glass is still not fully understood as a function of cutting configuration. Kevin Foy et al studied the effect of tilt angle along the feed direction on cutting regime transition in micro milling crown glass with a micro-ball end mill. It is found that a crack-free glass surface can be better machined in the ductile mode using a 45degree tilt angle and feed rates up to 0.32mm/min. The tool used was a TiAlN coated cemented carbide ball end mill with 2 flutes having a helix angle of 30degree and a 0.2mm nose radius. It was observed that the favourable ductile regime machining can produce a surface with average surface roughness less than 60nm using a 45 degree tilt angle. Smaller roughness values were obtained with 45 degree when compared to 60 degree.



Fig 14. End milling of glass

Cheng et al developed a debris free laser direct writing method to fabricate glass chip. Liu et al evaluated cutting performance of soda lime glass using an ultraprecision lathe with a single crystal diamond tool. Matsumura and Ono discussed a cutting process using ball end mills for machining microgrooves on glass. Orthogonal grooves 15-20µm deep and 150-175µm wide were machined. Ilescu et al fabricated a through hole in 500µm thick pyrex glass wafer using chemical wet etching. Yan et al used microstructure arrays as moulds for hot press glass moulding experiments.

Chien Yao Huang et al developed a glass biochip fabrication by laser micromachining and glass moulding process. The moulds used in glass moulding process must have high stiffness and no adhesion characteristics. Common materials used are stainless steel, silicon carbide, tungsten carbide, glassy carbon. SiC is a brittle and non conductive material. Due to SiC's high absorption of laser wavelength and high pulse energy the laser micromachining technique can quickly fabricate various structures on the mould surface. Steps of precision glass moulding are shown in the figure.15



Fig 15. Glass moulding process

Optimal parameters included a 620 degree C temperature, 1 kN pressing force, 5 mm/min speed, 60 sec temperature holding time, and a vacuum-free environment. These optimal parameters formed micro channels measuring 200µm wide and 185µm deep, with a surface roughness of 0.7µm (Ra).

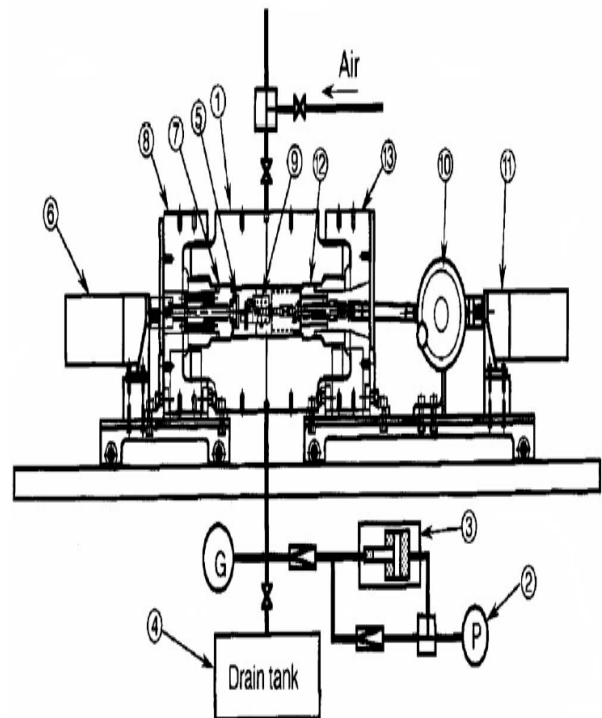
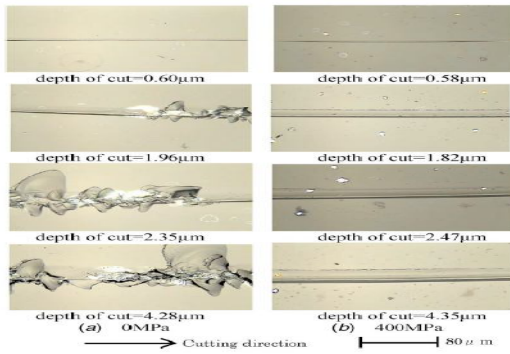


Fig 16. Machining under external hydrostatic pressure

Fig 17. Different results obtained



Masahiko Yoshino et al reported on the development of a machining device which is capable of carrying out precision machining experiments under external hydrostatic pressure. Machining trials were carried out on hard brittle materials such as soda glass, quartz glass under the externally applied hydrostatic pressure of zero and 400MPa. The construction of the

machining device is given below. A single point diamond tool is used for the machining purpose. Turbine oil is used as the pressure medium in these experiments. Photographs of grooves and cracks on soda glass plate generated by the machining tests are shown in the figure.

Mashiko Yoshino et al reported on nanosurface fabrication of hard brittle materials by structured diamond tool imprinting. Ultrafine structured surfaces were fabricated on soda glass, firelite glass, quartz glass, quartz wafer, and silicon. A specially designed and developed nanoindentation tester and a structured diamond tool machined by Focused Ion Beam (FIB) are used for the generation of such surfaces.

DISCUSSIONS AND CONCLUSION

S.No.	METHODS AND PROCESSES	DISCUSSION
1	ELID Grinding	Used to alleviate wheel loading for fine grit size metal bond wheels
		Recommended for use in efficient precision grinding
2	Abrasive water jet machining	Taper of cut directly proportional to SOD and feed rate
		Taper of cut indirectly proportional to increase in pressure
		Width of cut directly proportional to SOD and increase in pressure
		Width of cut indirectly proportional to feed rate
		No residual stresses
3	Laser micromachining using absorbent slurry	Machining depth increased as pulse energy increased
		Groove depth directly proportional to absorbent concentration and pulse frequency
4	Chemical assisted ultrasonic machining of glass	Surface roughness and MRR were improved up to 40% at micro drilling and 200% at macro drilling
		Machining load also reduced
		Enlarges the size of the machining hole to a certain extent
5	Development of grinding drilling technique	Simple, cost effective, environmental friendly, readily controllable method compared to ultrasonic vibration assisted method or chemical etching

6	Diamond cutting of glass	Conventional grinding has an accuracy of $3\mu\text{m}$ at a cost of \$50000 with a fabrication time of 12 months whereas diamond turning has an accuracy of $0.6\mu\text{m}$ at a cost of \$4000 with a fabrication time of 3 weeks
7	Glass micro milling with tilted tool	At 45 and 60 degree no fractured surfaces were noticed
		Average surface roughness less than 60nm
8	Electrochemical discharge machining for slicing glass	Used to slice 10-30mm diameter optical glass
9	Glass biochip fabrication by laser micromachining	Channels $200\mu\text{m}$ wide and $185\mu\text{m}$ deep with Ra of $0.7\mu\text{m}$ were obtained
10	Machining glass by dual CO2 laser beam	Used in flat panel display industry
		Reduces the possibility of fracture in the process of cutting glass by lasers
11	Machining of glass by single point tool under external hydrostatic pressure	Reduced cracks and chipping
		Enhanced limit of ductile mode machining
		Depth of cut $0.58\mu\text{m}$ - $4.35\mu\text{m}$ and a very good surface finish
12	Magneto rheological finishing of glass	Surface roughness obtained $0.9\mu\text{m}$ to $1.4\mu\text{m}$
13	Micro electrochemical discharge cutting of glass using surface textured tool	Decrease in value of voltage by 10VDC and enhanced spark frequency of 1.5KHz
		Surface roughness of $0.3\mu\text{m}$ for cutting glass of thickness of 0.4mm
14	Micro texturing channel surfaces on glass with spark assisted chemical engraving	Channels machined at low speed ($5\mu\text{m/s}$) had uniform texture
15	Micromachining with Electrochemical discharge machining	Micro channels machined with 0.12 to 0.2mm depth
		Applied voltage most influencing parameter
16	Nano abrasion machining of glass	low collision energy and shallow collision angle lead to abrasion rate few nanometres per minute
		Ra of 10-40nm for BK 7 glass obtained
		Ra of 5-20nm for Zerodur glass obtained

17	Non abrasive polishing of glass	Angstrom order surface roughness can be obtained
		Ra obtained 0.48nm for K9 glass
18	Electrochemical spark machining with abrasive cutting tools	better MRR and depth of cut is obtained
		surface roughness improves with increase in supply voltage
19	Machining using short pulsed lasers	NdYVO4 laser at 532nm wavelength and pulse width 3ns is used
20	Laser produced charged particles enabled machining	The impingement of high temperature , high speed electrons and low energy ions in the under dense region of the laser produced plasma is responsible for this high precision machining
21	Float polishing of glass	In some cases ideal surface roughness is obtained

A review of literature shows that various kinds of machining methods have been developed in the recent future for carrying out the precision machining operations on different types of glass. The ECDM method is the most commonly used method followed by laser micromachining using different sources of laser. Diamond micromachining is also becoming widely popular and the ductile regime machining of glass has been extensively studied to carry out precision machining. Abrasive jet machining has also been widely used for the machining on glass. Research is going on in finding the optimal parameters. Different methods of polishing of glass have also been looked upon. With the current trend finishing up to the angstrom level is possible in glass using the different methods.

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EXTERNAL AERODYNAMICS AND COOLING EFFECT OF PASSENGER CAR BRAKING SYSTEM USING CFD

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Abstract: Braking system is one of the important control systems of an automotive. For many years the disc brakes have been used in automobiles for safe retardation of the vehicles. During braking enormous amount of heat will be generated and for effective braking sufficient heat dissipation is essential. The thermal performance of disc brake depends upon the characteristics of airflow around the brake rotor and hence the aerodynamics is an important in the region of brake components. This project aims at maximizing the airflow distribution across the rotor for better heat dissipation and improving the cooling efficiency. A CFD analysis is carried out on the Skoda Octavia car braking system as a case study to make out the behaviour of airflow distribution around the disc brake components using FLUENT software. The result obtained from this analysis gives an insight idea of the airflow distribution around the brake rotor in order to minimize the temperature that affects the braking performance. Based on the results obtained, three new concepts were generated by incorporating air ducts guiding the air towards brake rotor to enhance the cooling effects. The results obtained for all the cases are analysed for effective cooling. From the results of temperature distribution it was observed that there is a considerable reduction in the max temperature generated during braking. 24°C (611°C to 587°C) decreased in maximum temperature for concept1 (air duct attached from bumper to disc rotor) and 41°C for concept2 (wish bone type) by properly guiding air towards brake rotor. A 110°C decrease was observed in concept3 (AL MMC) is achieved by incorporating an aluminium metal matrix composite material for the brake disc rotor.

Keywords:- Ventilated disc brake, Heat dissipation, CFD, Air flow, Cooling effect

1.0 INTRODUCTION

A braking system is one of the most important safety components of an automobile. It is mainly used to decelerate vehicles from an initial speed to a given speed. In some vehicles, the kinetic energy is able to be converted to electric energy and stored into batteries for future usage. These types of vehicles are known as electric or hybrid vehicles. However, these kinds of vehicles still need a backup system due to sometimes insufficient electric energy or failures which inevitably increase the cost of the vehicles. So friction based braking systems are still the common device to convert kinetic energy into thermal energy, through friction between the brake pads and the rotor faces.

Excessive thermal loading can result in surface cracking, judder and high wear of the rubbing surfaces. High temperatures can also lead to overheating of brake fluid, seals and other components

Braking system is one of the most essential mechanisms of a vehicle as shown in Fig.1.1. It is implicit that the braking system must be able to eliminate the kinetic and potential energy to facilitate a safe deceleration. Generally, the methodologies like regenerative-braking and friction-braking system are used in a vehicle. Due to limitations of Regenerative-braking system, friction based braking system is universally adopted for retardation of vehicles. Friction-brakes function by transforming the vehicles kinetic and potential energy into heat energy

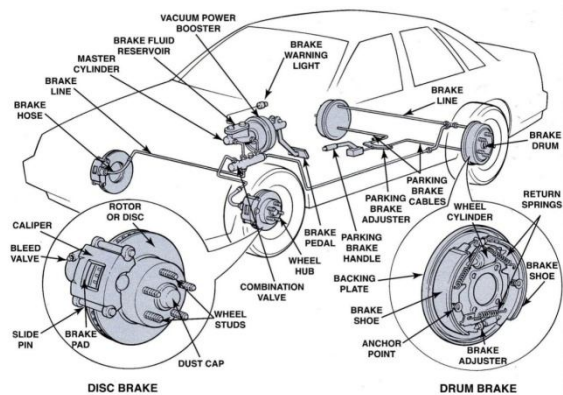


Fig1.1 Shows the layout of braking system

The rate of heat generation in a friction-braking system is a function of the vehicles mass, velocity and rate of deceleration. When the brakes are applied a large amount of heat is generated in a brake system accordingly the surrounding brake components has to absorb the heat within a shorter period of time, but it is capable of storing only a limited amount of heat produced during braking. In addition, the efficient dissipation of heat is instrumental to the performance of the braking system.

If the temperatures go too high, problems in braking system crop up from wear and tear of components by screeching and rapid vibration to permanent dysfunction of braking systems. Figure 1.2 shows the heat generated at the initial stage of brake

rotor and pads comes in contact. When a sudden brake is applied for a vehicle moving at a high velocity due to friction, more heat is generated during frequent braking is shown in Figure 1.3. Some of the factors that affect disc brake due to high temperature are brake fade; thermal judder and excessive component wear as shown in Figure 1.4. Therefore, it is beyond doubt that the methods of cooling the components of a brake system are to be improved to minimize the risk of the problems and enable safer vehicular movement.

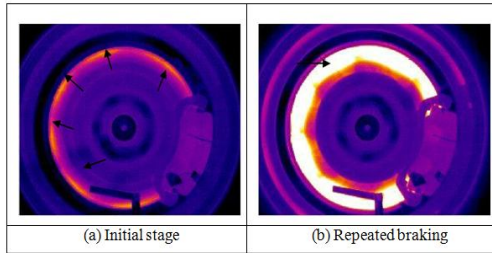


Fig 1.2 Shows heat generated between rotor and pad

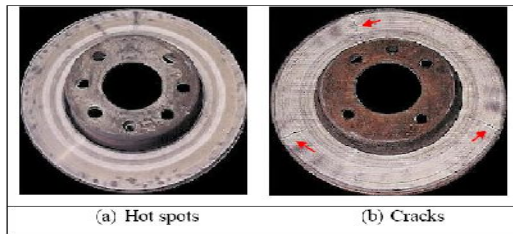


Fig 1.3 Shows overheating of brake pad

Though at first, the heat is absorbed by the surrounding components, later, continued braking radiates heat to the adjoining components through conduction and convection through atmosphere. Conduction is an effective method of heat dissipation but certain components get adversely affected. Sometimes when high temperatures are not controlled, they damage the tires of the vehicle. Therefore, convection to the atmosphere is the principal means to dissipate heat from the brake rotor. Normally, the forward movement of the vehicle directs the cooling air at the brake to transfer convection heat. So in order to achieve maximum cooling of the brakes, airflow must be regulated and directed to appropriate areas.

2.0 LITERATURE REVIEW

Much attention has been focused on improving the thermal performance of brake discs. Numerical simulations and Computational Fluid Dynamics (CFD) are commonly applied to brake disc thermal performance analyses. Many experimental studies have also been conducted to measure the air flow and temperature field inside the discs under braking operations. It has been demonstrated that CFD simulation results have achieved good agreement with those based on experimental studies. By study of literature, we came to know that, Numerical

simulation investigation can be done by properly guiding the airflow from the front end of a car towards the wheel. Conventional method is considered as the best method to dissipate heat because it's dependent on speed which can be controlled. Improvements can be done by modifying the dimensional characteristics of ventilated vane disc rotor to enhance good airflow and heat dissipation characteristics. The component of disc brake assembly tries to transfer better heat to the surrounding air. The front end design approach influence the importance of bumper and grill design. This project aims at maximizing the airflow distribution across the rotor for better heat dissipation and improving the cooling efficiency.

3.0 ANALYTICAL MODEL

For fluid flow and heat transfer analysis across brake rotor, the governing equations, such as continuity equation, momentum (Navier Stokes) equation and energy equations are used in CFD for solving the solution

Continuity equation: A continuity equation is a based on the principle of conservation of mass. For steady state it states that the mass of fluid entering a fixed control volume either leaves that volume or accumulates within it is constant. It is thus a "mass balance" requirement posed in mathematical form, and is a scalar equation.

$$\frac{\partial \rho}{\partial t} + \frac{\partial(\rho \cdot u)}{\partial x} + \frac{\partial(\rho \cdot v)}{\partial y} + \frac{\partial(\rho \cdot w)}{\partial z} = 0 \dots(3.1)$$

Momentum (Navier Stokes) equations: The momentum equation is a statement of Newton's second law and relates the sum of force acting on an element to its acceleration. Hence $F=ma$ which forms the basis of the momentum equations. The three different momentum equations (x, y and z), altogether comprise the Navier Stokes equations that describe the flow of incompressible fluids.

$$\begin{aligned} \rho \frac{\partial u}{\partial t} + \rho u \frac{\partial u}{\partial x} + \rho v \frac{\partial u}{\partial y} + \rho w \frac{\partial u}{\partial z} &= \rho g_x - \frac{\partial p}{\partial x} + \mu \frac{\partial^2 u}{\partial x^2} + \mu \frac{\partial^2 u}{\partial y^2} \\ &+ \mu \frac{\partial^2 u}{\partial z^2} \\ \rho \frac{\partial v}{\partial t} + \rho u \frac{\partial v}{\partial x} + \rho v \frac{\partial v}{\partial y} + \rho w \frac{\partial v}{\partial z} &= \rho g_y - \frac{\partial p}{\partial x} + \mu \frac{\partial^2 v}{\partial x^2} + \mu \frac{\partial^2 v}{\partial y^2} \\ &+ \mu \frac{\partial^2 v}{\partial z^2} \\ \rho \frac{\partial w}{\partial t} + \rho u \frac{\partial w}{\partial x} + \rho v \frac{\partial w}{\partial y} + \rho w \frac{\partial w}{\partial z} &= \rho g_z - \frac{\partial p}{\partial x} + \mu \frac{\partial^2 w}{\partial x^2} + \mu \frac{\partial^2 w}{\partial y^2} \\ &+ \mu \frac{\partial^2 w}{\partial z^2} \end{aligned} \dots(3.2)$$

Energy equations: The continuity and momentum equations are adequate in situations, where the fluid

is incompressible and the temperature differences are small. If the heat flux occurs (temperature not constant) an additional equation (energy) is enabled. An energy equation is a scalar equation. It has no particular direction associated with it. This equation demonstrates that, per unit volume, the change in energy of the fluid moving through a control volume is equal to the rate of heat transferred into the control volume plus the rate of work done by surface forces plus the rate of work done by gravity

$$\begin{aligned} & \frac{\partial}{\partial t} \left(\rho e + \frac{1}{2} \rho v^2 \right) + \frac{\partial}{\partial x} \left(\rho u e + \frac{1}{2} \rho u v^2 \right) \\ & + \frac{\partial}{\partial y} \left(\rho v e + \frac{1}{2} \rho v v^2 \right) + \frac{\partial}{\partial z} \left(\rho w e + \frac{1}{2} \rho w v^2 \right) = \\ & k \left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2} \right) - \left(u \frac{\partial p}{\partial x} + v \frac{\partial p}{\partial y} + w \frac{\partial p}{\partial z} \right) + \\ & \mu \left[u \frac{\partial^2 u}{\partial x^2} + \frac{\partial}{\partial x} \left(v \frac{\partial v}{\partial x} + w \frac{\partial w}{\partial x} \right) + v \frac{\partial^2 u}{\partial y^2} \right. \\ & + \frac{\partial}{\partial y} \left(v \frac{\partial u}{\partial y} + w \frac{\partial w}{\partial y} \right) + w \frac{\partial^2 u}{\partial z^2} \\ & + \left. \frac{\partial}{\partial z} \left(v \frac{\partial v}{\partial z} + u \frac{\partial u}{\partial z} \right) \right] \\ & + 2\mu \left[\frac{\partial^2 u}{\partial x^2} + \frac{\partial u}{\partial y} \frac{\partial v}{\partial x} + \frac{\partial^2 v}{\partial y^2} + \frac{\partial v}{\partial z} \frac{\partial w}{\partial y} + \frac{\partial^2 w}{\partial z^2} + \frac{\partial w}{\partial x} \frac{\partial u}{\partial z} \right] \\ & + \rho u g_x + \rho v g_y + \rho w g_z \end{aligned} \quad (3.3)$$

Turbulence model: A standard k-ε model is selected with reference to Rolf Krusemann and Gerald Schmidt [2]. It is a two-equation turbulence model derived from Reynolds Averaged Navier Stokes modeling. K is the turbulent kinetic energy, defined as the variance of the fluctuations in velocity and ε is the turbulence eddy dissipation rate at which the velocity fluctuations dissipate. This semi empirical model is robust and economic, most widely used in industrial and practical engineering turbulent flow problems, also suitable for parametric studies. The turbulence kinetic energy (k) and rate of dissipation (ε) is obtained from the following transport equations;

For turbulent kinetic energy:

$$\frac{\partial}{\partial t} (\rho k) + \frac{\partial}{\partial x_j} (\rho k u_j) = \frac{\partial}{\partial x_j} \left[\left(\mu + \frac{\mu_t}{\sigma_k} \right) \frac{\partial k}{\partial x_j} \right] + G_k - \rho \epsilon + S_k \quad (3.4)$$

And for rate of dissipation:

$$\begin{aligned} & \frac{\partial}{\partial t} (\rho \epsilon) + \frac{\partial}{\partial x_j} (\rho \epsilon u_j) = \frac{\partial}{\partial x_j} \left[\left(\mu + \frac{\mu_t}{\sigma_\epsilon} \right) \frac{\partial \epsilon}{\partial x_j} \right] + \\ & C_{1\epsilon} \frac{\epsilon}{k} G_k - C_{2\epsilon} \rho \frac{\epsilon^2}{k} + S_\epsilon \end{aligned} \quad (3.5)$$

The turbulent viscosity, μ_t is computed by combining K and ε as follows,

$$\mu_t = \rho C_\mu \frac{k^2}{\epsilon} \quad (3.6)$$

3.2 Brake heat transfer

Fig 3.2 shows the schematic shape of the disk and the pad in sliding contact is shown. As it is shown disk is like an annulus and pad is like a partial annulus. The brake system clamps the pads through the calliper assembly by brake fluid pressure in the cylinders. Rotary motion of the disk causes a sliding

contact between the disk and the pad and generates heat

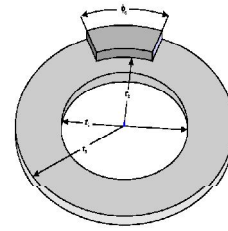


Fig: 3.1 shows schematic shape of the disk and the pad in sliding contact

For calculation of heat generation due to friction, rate of dissipated heat via friction should be taken into account. This is all to do with the calculation of friction force and rate of work done by friction force. For calculation of friction force, the pressure distribution at the contact surface of the disk and the pad should be determined. Here, two types of pressure distribution are taken into account.

In the contact area of brake components; the pads and the disk; heat is generated due to friction. For calculation of heat generation at the interface of these two sliding bodies' two methods is suggested:

1. At the basis of law of conservation of energy the kinetic energy of the vehicle during motion is equal to the dissipated heat after vehicle stop
2. By knowing the friction coefficient, pressure distribution at the contact area, geometric characteristics of the pad and the disk, relative sliding velocity and duration of braking action one can calculate the heat generated due to friction

Brakes are essentially a mechanism to change the energy types. When a car is moving with speed, it has kinetic energy. Applying the brakes, the pads or shoes that press against the brake drum or rotor convert this energy into thermal energy. The cooling of the brakes dissipates the heat and the vehicle slows down. This is all to do with the first law of thermodynamics, sometimes known as the law of conservation of energy that states that energy cannot be created nor destroyed; it can only be converted from one form to another. In the case of brakes, it is converted from kinetic energy to thermal energy:

The different modes of heat dissipation are;

1. Conduction through the brake assembly and hub
2. Radiation to nearby components
3. Convection to the atmosphere

Conduction is an effective mode of heat transfer but it affects the adjoining components in terms of damaging the seals, bearing etc.

Radiation heat transfer has the maximum effect of temperature that is to be controlled and it is estimated as negligible during normal braking conditions. So the convection is considered as primary means of heat dissipation from the brake rotor to the atmosphere. The Figure 3.2 shows the

schematic form of heat transfer mechanism in a disc brake system.

As for conduction through surfaces, the heat flow can be expressed by Fourier's law of conduction as follows

$$Q_{cond} = -kA \frac{dT}{dx} \dots (3.7)$$

Where, Q_{cond} is the heat transferred, k is the thermal conductivity, A is the area of contact and T is the temperature.

Similarly, the heat is transferred by convection, also known as Newton's law of cooling is governed by,

$$Q_{conv} = hA(T_s - T_{\infty}) \dots (3.8)$$

Where, Q_{conv} = Rate of heat transfer (W)

h = convection heat transfer coefficient (W/m²K)

A = surface area of the rotor (m²)

T_s = surface temperature of the brake rotor (°C)

T_{∞} = Ambient air temperature (°C)

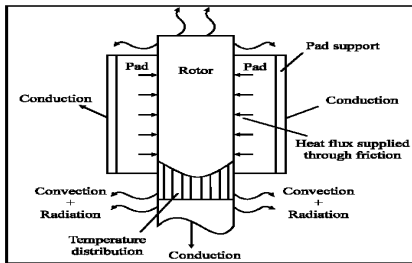


Fig3.2: Shows the heat transfer mechanism in brake system

4.0 GEOMETRIC MODELING AND CFD ANALYSIS

In this chapter the study of airflow distribution is carried out on the existing disc brake of Skoda Octavia passenger car as case study in order to reduce the temperature by guiding air towards brake rotor. The overall dimensions of car body and brake components are illustrated in Table 4.1

Tables 4.1:- Shows the specification of Skoda Car

All dimension are in mm	
Overall Length	4512
Overall width	1731
Overall height	1431
Wheel base	2512
Ground clearance	134
Front track	1513
Rear track	1494
Kerb weight	1330 Kg
Front brakes	Disc brakes
Rear brakes	Drum brakes
Front suspension	McPherson Sturt with wish bone arms
Rear suspension	Compound link crank axle with torsion stabilizer
Brake Disc (Size)	270Dia X 22
Brake pads	115 X 50 X 20
Tires	196/65 R15
Wheel size	6J X 15"

Calculation for input parameters: The heat flux is calculated for the car moving with a velocity 22.22 m/s (80 kmph) and the following is the calculation procedure

Data given:

1. Mass of the vehicle = 1330 kg [Table 3.1]
2. Initial velocity (u) = 22.22 m/s (80 kmph)
3. Final velocity (v) = 0 m/s
4. Brake rotor diameter = 0.270 m

Assuming, full load condition (100 % braking condition)

Energy generated during braking= 44324.46J

Stopping distance (D) = 35.94 m

Heat generated / volume (q)= 1.5×10^7 W/m³

4.1 Geometric model

The vehicle used for the simulation is Skoda Octavia 1.9TDI, a four door passenger car. Knowing the flow is to be analysed the geometric modelling is constructed using CAD software tool(CATIA V5R16).



Fig 4.1:- Shows 3D geometric model of Car

4.2 Domain creation

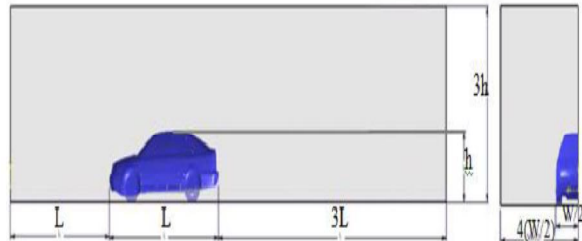


Fig 4.2:- Shows the domain creation

Table 4.1:- Shows the overall dimension of domain creation

Domain length	22500 mm
Domain width	6800 mm
Domain height	4500 mm

4.4 Meshing (Pre-processor)

To output the solution, the above tasks are carried out with the interaction between the user and the computer. This stage is done with the software Hyper Mesh, linked to the FLUENT software

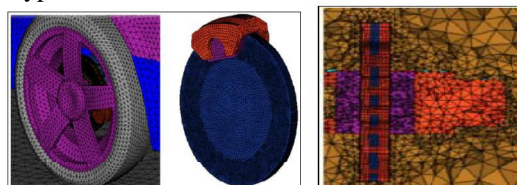


Fig 4.3:- Shows the fine mesh around the wheel and disc brake

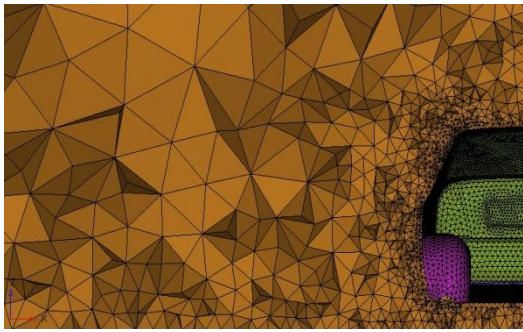


Fig 4.4:- Shows the fine tetra mesh around the surface of body

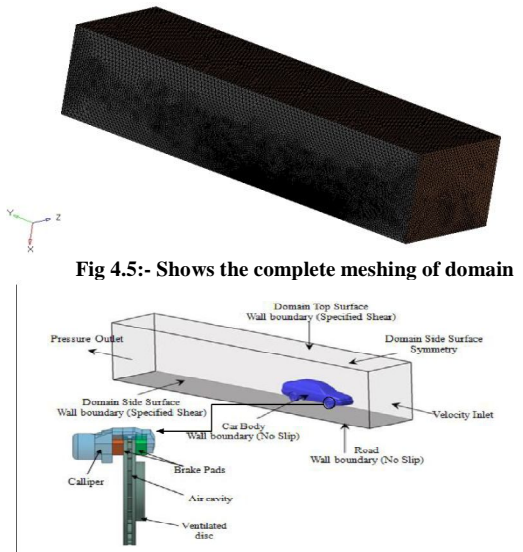


Fig 4.5:- Shows the complete meshing of domain

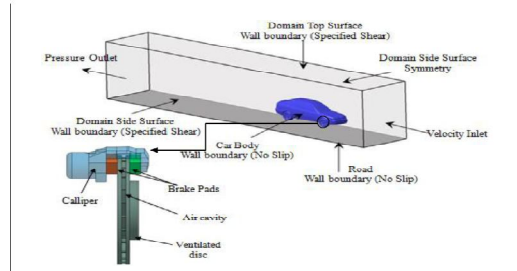


Fig 4.6:- Shows the boundary condition

4.5 CFD Analysis

CFD is primarily used as a design aid for predicting the performance characteristics of equipment involving fluid flow and heat transfer. It's capability to achieve fast and reliable convergence by solving the equations precisely.

Solver setting and importance:

Table 4.2:- Shows the input parameter for solution

Solver	Segregated
Formulation	Implicit
Time	Steady state
Velocity Formulation	Absolute
Pressure discretization	Standard
Momentum discretization	First order upwind
Turbulent kinetic energy	First order upwind
Specific dissipation rate (omega)	First order upwind
Pressure velocity coupling	SIMPLE

Turbulent intensity and viscosity was to specify the turbulence specification method and is defined as the ratio of root mean square of the

velocity fluctuations to the mean flow velocity expressed by,

$$I = 0.16(R_e)^{-\frac{1}{8}} \quad \text{--- (3.14)}$$

$$\text{Reynolds number } R_e = \frac{\rho v l}{\mu} \quad \text{---- (3.15)}$$

Where 'ρ' is the density of fluid (Kg/m³)

'v' is the velocity of fluid (m/s)

'l' is the length of the obstacle (m)

'μ' is the co-efficient of viscosity

The Reynolds number and Mach number is calculated and mentioned in the following Table

Table 4.4:- Illustrates the solver parameters

For Velocity 22.22 m/s	
Mach number	0.1
Reynolds number	686497
Turbulent intensity	2.6

The material properties for disc rotor and pad such as thermal conductivity, specific heat and density are illustrated in the following Table 3.5

Table 4.5:- Shows the material properties of brake rotor and pad

Component	Brake rotor	Brake pad
Material	Grey cast iron	Asbestos
Density Kg/	7100	3500
Co-efficient of heat j/Kg - °K	45	800
Thermal conductivity (K) W/m-°K	46	4

4.5.1 Solution for existing model

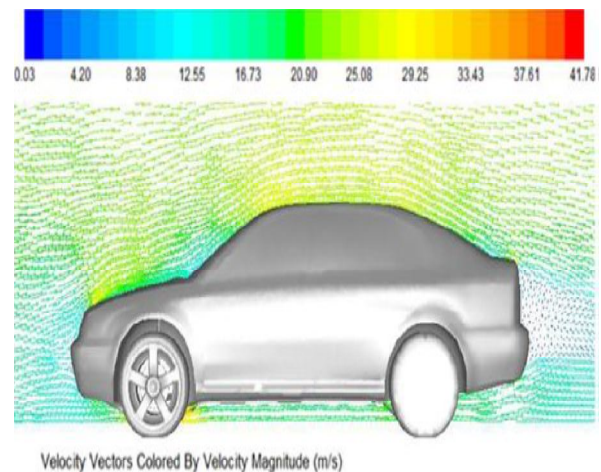


Fig 4.7:- Shows velocity vectors for baseline model at a velocity 22.22m/s

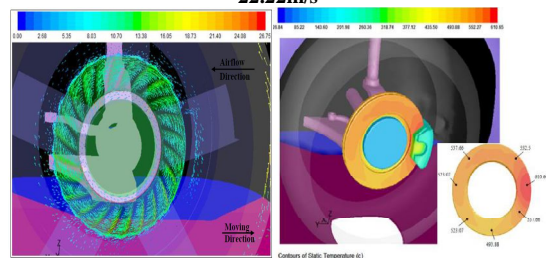


Fig 4.8:- Shows airflow pattern at the lateral section and temperature contours of ventilated brake rotor

Figure 4.8 shows the contours of static temperature distribution for the baseline model across the brake rotor. It is observed that the maximum temperature 610.64°.

4.5.2 Approach of design improvement:

Due to friction the higher temperature in the brake rotor thermal stress are generated that affects higher thermal stresses are induced at high temperature that affects the performance during braking. The affects may leads to crack, brake judder, spots etc. and in order to minimize the high temperature, the three different concepts are generated inconsideration of brake cooling performance.

4.5.2.1 Concept 1 (Air Duct attached from bumper to disc brake)

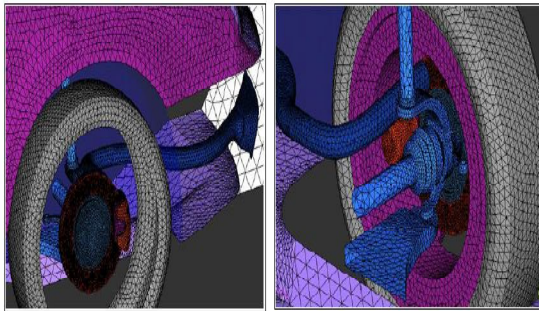


Fig 4.9:- shows meshing of concept1

4.5.2.1 Concept 2 (Wish bone)

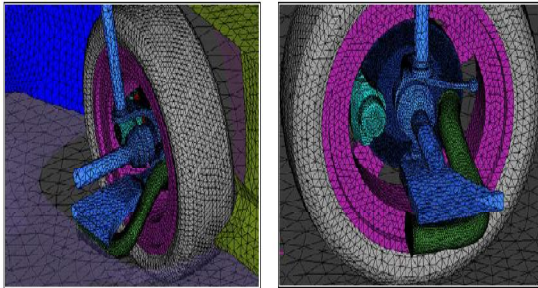


Fig 4.10:- Shows meshing for concept2

5.0 RESULTS AND DISCUSSION

Figure 5.1 shows the contours of static temperature distribution for the baseline model across the brake rotor. The maximum temperature observed is 610.64°C in between the pad and the rotor

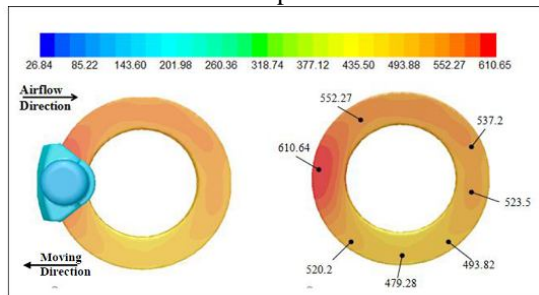


Fig 5.1:- Shows contours of temperature distribution across brake rotor

Figure 5.2 shows the contours of static temperature distribution for the modified model across the brake rotor. The maximum temperature observed is 586.21°C in between the pad and the rotor.

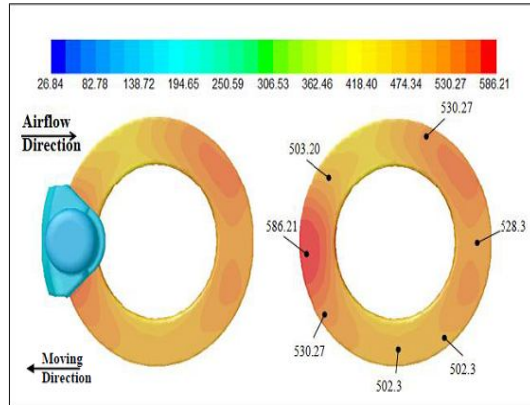


Fig 5.2:-Shows contours of temperature distribution across brake rotor

The Figure 5.3 shows the contours of static temperature distribution for the modified model across the brake rotor. The maximum temperature observed is 569.45°C in between the pad and the rotor.

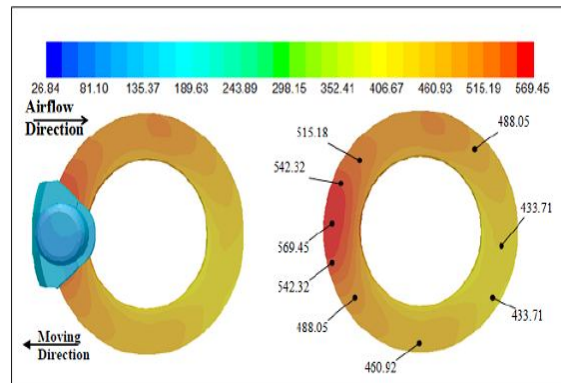


Fig 5.3:- Shows contours of temperature distribution across brake rotor

6.0 CONCLUSION

A detailed study of the flow across the disc brake rotor and the suggestion for the new design concepts has been carried out. Following are the conclusions based on the analysis results;

1. The results achieved through CFD with acceptable accuracy for the baseline and the modified concepts help in understanding and visualizing the airflow across the brake rotor.
2. The brake rotor serves as energy dissipater, so to achieve this better additional air is guided to provide an adequate cooling.
3. The modified design concepts are found to be effective in terms of temperature reduction with increased airflow.

From the results of temperature distribution it was observed that there is a considerable reduction in the max temperature generated during braking. 24°C (611°C to 587°C) decreased in maximum temperature for concept1 (air duct attached from bumper to disc rotor) and 41°C for concept2 (wish bone type) by properly guiding air towards brake rotor.

SCOPE FOR FUTURE WORK

1. In addition to steady state analysis transient analysis can be carried out to study the heat transfer across the disc brake.
2. Further the study of the heat transfer around the disc brake rotor may be done considering the radiation.
3. Further investigation through CFD analysis can be carried out considering the rear disc brake to study the airflow distribution.

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“DEVELOPMENT OF MECHANIZED SYSTEM TO REPLACE MANUAL METHOD OF PRODUCING SLIVER IN KHADI MANUFACTURING”.

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Abstract- The economic situation of khadi industry and the extremely sharp worldwide competition with textile industry have forced the khadi industry to use all possibilities of cutting cost. In this context, the question of higher production at each stage of khadi manufacturing gains importance. Now a days, khadi has become so popular that internationally renowned fashion designers also prefer to use it. As per the Khadi & Village Industries Associations survey the sales of Khadi is massively increase year by year from 2001 to 2011 sales of khadi is increased upto Rs.- 511.71 Crores. To satisfied such a increasing demand with lower cost, khadi industries needed some mechanized system to increased production rate. In khadi industries the sliver is produce manually. This is time consuming process which is directly effect on cost of khadi. This problem taken into consideration for project work. In this paper we try to developed mechanized system to replace manual method of sliver producing. This project seeks to Analysis and Functional enhancement of Pinjanalaya carding Machine to produce sliver and use to discover a new tool to shorten the sequence for producing the sliver. This may lead to significant savings of time and cost, and thus improve the competitiveness of the Indian Khadi Udyog as well as provide more profit to the farmer.

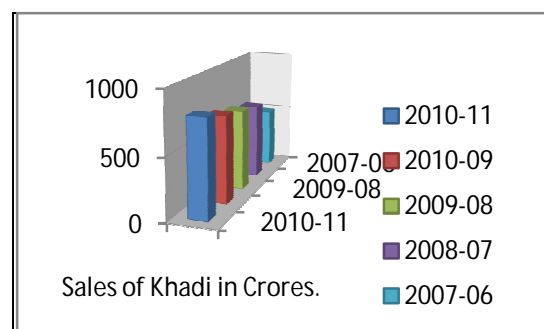
Keyword :- Sliver, carding machine, Fiber, khadi industry.

I. INTRODUCTION:

In textile industries the Carding Machine is use for producing sliver which is very costly. In case of khadi industries Carding machine is use only for separation of fiber from the cotton & to removal impurity present in the cotton. After Carding process sliver (Pelu) is produce manually. This is time consuming process which is directly effect on cost of khadi. The another carding machine that is “Pinjanalaya Carding machine” having somewhat same function which is used in “Pinjanalaya Center” for opening of fiber & remove impurity from the cotton. Which cost is comparatively less than Textile industries Carding Machine. But this Pinjanalaya carding machine is not able to produce Sliver. This problem taken into consideration for project work. In which we going to develop mechanized system to replace manual method of sliver producing. By functional enhancement of Pinjanalaya carding machine with minimizing the cost.

Khadi & Village Industries Commission (KVIC) established under the Khadi and Village Industries Commission Act, 1956 (61 of 1956), is a statutory organization engaged in promoting and developing khadi and village industries for providing employment opportunities in the rural areas, thereby strengthening the rural economy of the country.

Due to effort of KVIC the sales of Khadi is increasing day by day in 2006-07 it was 491.52 crores, now in 2010-11 it was 789.87 crores.



Year	Sales in Crores
2010-11	789.87
2010-09	712.26
2009-08	663.19
2008-07	618.12
2007-06	491.52

To satisfied such a increasing demand with lower cost, khadi industries needed some mechanized system to increased production rate.

II. LITERATURE REVIEW:-

Y. Wang (Leader), Georgia Tech (National Textile Center Annual Report: November 2001) presented a project on “Analysis and enhancement of carding and spinning”. In this project they enhance the fundamental understanding of carding and spinning, and to use the discovery as a new tool to shorten the sequence for staple yarn processing. This may lead to

significant savings, and thus improve the competitiveness of the US textile industry M. Lee and H. Ockendon (BP Institute for Multiphase Flow, University of Cambridge), Journal of Engineering Mathematics (2006) have provided excellent literature for understanding the transfer of fibres between carding-machine surfaces by considering the movement of a single fibre in an airflow. Understanding the mechanisms for fibre transfer between carding surfaces, will provide much needed insight into general fibre dynamics during the process, machine design and process control optimization, and the formation of the sliver. They provide model behavior of a single fibre in the transfer regions of a carding machine, and these results could easily be extended to consider many fibres in a dilute suspension. The approach of the work in this paper is in some sense a natural extension of the static analysis, which considers frictional forces acting on a single fibre in tension, held by two hooks on opposing carding surfaces. by this paper they attempt to answer the question is “When does this scenario occur and, in particular, how are fibres that are tethered to a hook on one carding surface presented to the hooks on another carding surface?”

III. SURVEY OF INDUSTRY:

The basic process of sliver producing required raw material of cotton which is came from carding .In case of textile industry carding machine is use which is very costly & for Khadi industry this operation is done manually. So we try to develop a mechanism from Carding Machine (Pinjanalaya) which cost is comparatively so less. which can be buy by Vidarbha’s farmers. The Survey is conducted to on various Panjanalaya Center (Pinjanalaya Carding machine.) in order to find out Range of speed in which carding is perform to get high Quality cotton & to understand the mechanized system of Pinjanalaya carding machine. We also visit the Main center of Maharashtra KhadiUdyog , Sewagram, & Gram SewaMandal ,Gopuri, Wardha .which was developed by the father of nation Mahatma Gandhi. For study & analysis of khadi manufacturing as well as various process of charakha manufacturing. In order to find out various quality requirements of Sliver & its specification.

IV. CURRENT SLIVER PRODUCING METHOD :

In olden days slivering process and is done with a bow like instrument to fluff cotton and to create rolls called slivers. These are handmade and kept in dried banana stems to use to procure the thread.



Fig.- manual method of producing Sliver (Pelu).

While in case Textile industry Sliver is produce with the help of Carding Machine .This is continuous sliver. The cost of this machine is around Rs-12 lacks to Rs-15 lakhs. The “ Pinjanalaya Carding machine” use in Pinjanalaya Centre for opening of cotton fiber & removal of impurity. Which having cost around Rs.-2 lacks.



Fig. - Carding Machine use in Textile Industry and Pinjanalaya Carding Machin

Still now a day same process is adapted to produce sliver with minor changes .Device use for sliver producing in Main center of Maharashtra KhadiUdyog , Sewagram, & Gram SewaMandal ,Gopuri, Wardha



Fig.- Recent manual method of producing sliver(Pelu).

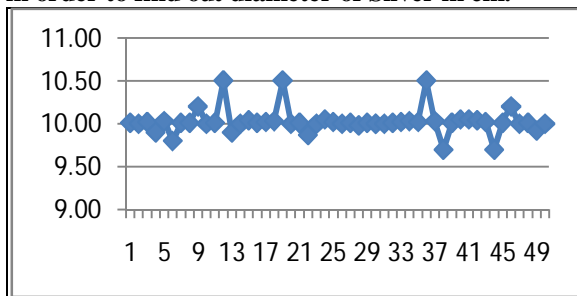
With the help of this device 1man or 1women can produce 3-3.5 kg sliver per day.

While In Khadi Gram Udyog ,Gopuri ,Wardhademand of sliver 400 to 500 kg per month Which is send to All Over Maharashtra Kerala, Hyderabad ,lakhanav as well as export to Japan, England, Italy .

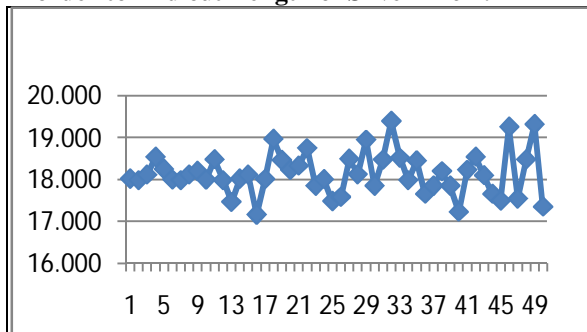
V. DATA COLLECTION :

Dimension of base plate(length 36 cm, width 17.5 cm, thicken) ,Pressing Pad(length = 14.5 cm, width = 14.5 cm, thickness= 1.5 cm, Weight of pad = 500gm.),Rod (Diameter = 0.5 cm, Length =24.5cm.),Sliver (Pelu) (Length =18 cm., Diameter = 1 cm,Weight of sliver = 1gm., Production rate = 3 - 3.5 kg/day/worker, Requirement of sliver = 450-500 kg month.).The actual reading have been taken for understanding the accuracy of work which is carried work at Main center of Maharashtra KhadiUdyog , Sewagram, & Gram SewaMandal ,Gopuri, Wardha.

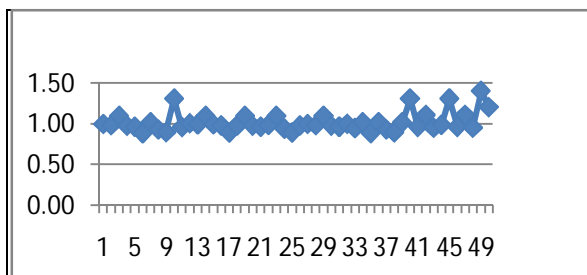
The actual Reading of 50Sliver (Pelu) take place in order to find out diameter of Sliver in cm.



The actual Reading of 50 Sliver (Pelu) take place in order to find out Length of Sliver in cm.



The actual Reading of 50 Sliver (Pelu) take place in order to find out Weight of Sliver in (Gram).



From the above graph it is found that the manual process of producing sliver is highly inaccurate.

VI. PROPOSED WORK :-

CONSTRUCTION :-

To solve above cited problem we propose mechanism in which the main carding roller is use for opening the fiber of cotton .which having number of teeth on its periphery as shown in fig. and having speed around 1440 rpm. Cotton fibers fed to the card by feed conveyers are separated from the batt in tufts by the lickerin. From the lickerin they are transferred to the main cylinder which move opposite direction with respective to the lickerin. The output of the main cylinder is then connected with the help of duct to the attachment whichhaving two revolving rod in between the two steady wooden plates.which is rotted with the help of stepper motor. The hook is used to remove thesliver from rod.

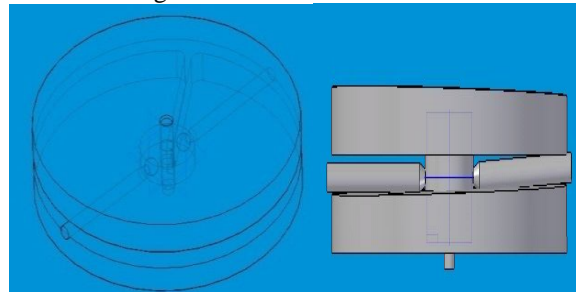


WORKING :

The carding conveyers, lickerinand main carding roller rotted with the help of motor. Which transfer cotton to main carding roller,due to high speed difference between lickerin and carding dram the cotton fiber get open and separated from each other. Because of high speed of carding dram the separated cotton fiber thrown from dram which is transfer to the other attachment with the help of duct.

This attachment having one round base plate and revolving assembly at center which is rotted with the help of setter motor.

Two rod is connected by using ball and socket joint as shown in figure .



This assembly is attach to the main carding dram with help of duct & due to the high velocity cotton fiber get collect in between two plate .Because of rough surface rotting rod ,the cotton fiber get wound around the rod, which can be remove with the help of hook with some predetermined time.

VII. CONCUSSION:

With the help of this mechanism we will be able to produce Sliver (Pelu) more efficiently & economic. which will helpful to khadi industry to increase production rate as well as reduce the cost. The main objective of this project to decentralization of Carding machine and provide a mechanism to specially “Vidarbha” rigionfarmar so that they will directly able to sell Sliver to khadi industry and get more profit. This project also lead to shorten the sequence of khadi production.

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EVALUATION OF OPTIMAL MACHINING PARAMETERS OF Nicrofer C263 ALLOY USING RESPONSE SURFACE METHODOLOGY WHILE TURNING ON CNC LATHE MACHINE

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Abstract The objective of the present work was to investigate the effects of the various machining (turning) process parameters on the machining quality and to obtain the optimal sets of process parameters so that the quality of machined parts can be optimized. The working ranges and levels of the machining process (turning) parameters are found using three factors. Cutting speed (V_c - m/min), feed rate (f - mm/rev) and depth of cut (d - mm). The Design-Expert software has been used to investigate the effects of the Machining process parameters and subsequently to predict sets of optimal parameters for optimum quality characteristics. The response surface methodology (RSM) in conjunction with second order central composite rotatable design has been used to develop the empirical models for response characteristics. Desirability functions have been used for simultaneous optimization of performance measures. Also, the ANOVA technique and utility function have been used for response optimization. Confirmation experiments are further conducted to validate the results.

Keywords: Cutting parameters; turning process; feed force; RSM(Response Surface Methodology); ANOVA; Nicrofer c-263, TiAlN coated carbide tool.

INTRODUCTION:

A manufacturing engineer or machine setup technician is often expected to utilize experience and published shop guidelines for determining the proper machining parameters to achieve a specified level of surface roughness. This must be done in a timely manner to avoid production delays, effectively to avoid defects, and the produced parts monitored for quality. Therefore, in this situation, it is prudent for the engineer or technician to use past experience to select parameters which will likely yield a surface roughness below that of the specified level, and perhaps make some parameter adjustments as time allows or quality control requires. A more methodical, or experimental, approach to setting parameters should be used to ensure that the operation meets the desired level of quality with given ambient conditions and without sacrificing production time. Rather than just setting a very low feed rate to assure a low surface roughness, for example, an experimental method might determine that a faster feed rate, in combination with other parameter settings, would produce the desired surface roughness.

LITERATURE REVIEW

- H.H. Habeeb, K. Kadirgama, M.M. Noor, M.M. Rahman, B. Mohammed, R.A. Bakar and K. A. Abouel Hossein, et al. ,2010, pages 2322-2327, Journal Of Applied Science, Journal “Machining of Nickel Alloy 242 with Cubic Boron Nitride Tools” discusses the development of first and second order of surface roughness prediction model when machining Haynes 242 alloy with Cubic Boron Nitride (CBN). The relationship

between the cutting parameters (cutting speed, axial depth and feed rate) with surface roughness are discussed. Response Surface Method (RSM) has been selected to optimize the cutting parameters and reduce the number of experiments. Surface roughness obtained in these experiments ranged from 0.052-0.08 μm , which consider as an extremely fine finish. Increase in cutting speed from 70 to 300 m/min, the roughness getting finer. On the other hand, increase in feedrate (0.1 to 0.3 mm/tooth) and axial depth (0.025 to 0.075 mm) surface roughness become rougher.

- Aman Aggarwal, Hari Singh, Pradeep Kumar, Manmohan Singh, et al., 11 September 2007, pp 373-384, Journal Of Materials Processing Technology, Journal “Optimizing power consumption for CNC turned parts using response surface methodology and Taguchi’s technique—A comparative analysis” presents the findings of an experimental investigation into the effects of cutting speed, feed rate, depth of cut, nose radius and cutting environment in CNC turning of AISI P-20 tool steel. Design of experiment techniques, i.e. response surface methodology (RSM) and Taguchi’s technique; have been used to accomplish the objective of the experimental study. L27 orthogonal array and face centered central composite design have been used for conducting the experiments. Taguchi’s technique as well as 3D surface plots of RSM revealed that cryogenic environment is the most significant factor in minimizing power consumption followed by cutting speed and depth of cut. The effects of feed rate and nose

radius were found to be insignificant compared to other factors. Though both the techniques.

EXPERIMENTAL PROCEDURE:

1) First of all preliminary tests are done in order to find out the levels of machining parameters. First feed rate and depth of cut is kept constant and cutting speed is varied. The surface roughness of specimen is measured after each trial and it was found that optimum roughness is lying in between 50 to 100 m/min range of cutting speed. Next Speed is kept constant and feed rate is varied and surface roughness of the specimen is measured after each trial. The feed rate was found to be lying between 0.10 to 0.20 mm/rev for optimum surface roughness. Since according to literature depth of cut does not affect the surface roughness to a greater extent hence depth of cut levels were chosen according to the suitability.

2) After finding levels of parameters, design matrix as shown in table 5 was prepared with the help of Design Expert V 8.0 software.

3) Experiments were done as per the design matrix. The surface roughness was measured after each trial with the help of handysurf and all the data was recorded.

EXPERIMENTAL PLAN PROCEDURE:

Design Matrix with Responses:

RUN ORDER	STANDARD ORDER	SPEED (m/min)	FEED (mm/rev)	DOC (mm)	SURFACE ROUGHNESS (µm)
1	17	50.00	0.15	0.125	0.79
2	16	100.00	0.20	0.150	1.1
3	2	50.00	0.10	0.100	0.72
4	11	100.00	0.10	0.150	0.77
5	18	100	0.15	0.125	0.86
6	28	75	0.15	0.125	0.63
7	4	100	0.10	0.100	0.69
8	25	75	0.15	0.125	0.63
9	1	50	0.10	0.100	0.67
10	21	75	0.15	0.100	0.65
11	24	75	0.15	0.125	0.65
12	3	100	0.10	0.100	0.71
13	5	50	0.20	0.100	0.97
14	19	75	0.10	0.125	0.72
15	7	100	0.20	0.100	0.94
16	26	75	0.15	0.125	0.64
17	8	100	0.20	0.100	0.96
18	13	50	0.20	0.150	0.95
19	10	50	0.10	0.150	0.72
20	12	100	0.10	0.150	0.87
21	9	50	0.10	0.150	0.68
22	6	50	0.20	0.100	0.98
23	15	100	0.20	0.150	0.97
24	22	75	0.15	0.150	0.67
25	27	75	0.15	0.125	0.69
26	23	75	0.15	0.125	0.66
27	14	50	0.20	0.150	0.94
28	20	75	0.20	0.125	0.79

The data tabulated in the table 5.0 is analyzed with Design Expert V8.0 software. The analysis is shown and discussed here.

Table 5.1: Model Summary Statistics

Sequential	Lack of Fit	Adjusted	Predicted		
Source	p-value	p-value	R-Squared	R-Squared	
Linear	0.0011	< 0.0001	0.4185	0.3330	
2FI	0.7368	< 0.0001	0.3736	0.1927	
Quadratic	< 0.0001	0.0631	0.8884	0.7845	Suggested
Cubic					Aliased

Table 5.1 shows that quadratic model has to be applied for the observed sets of reading of surface roughness. It clearly shows that the quadratic model is the best suggested model for surface roughness with larger R² statistics value.

Table 5.2 - ANOVA for Surface Roughness Quadratic Model

Source	Sum of Squares	df	MEAN SQUARE	F VALUE	p-value Prob > F	
Model	0.48	9	0.053	24.88	< 0.0001	Significant
A-Speed	0.011	1	0.011	5.25	0.0342	
B-Feed	0.23	1	0.23	107.91	< 0.0001	
C-DOC	8.022E-003	1	8.022E-003	3.74	0.0689	
AB	9.000E-004	1	9.000E-004	0.42	0.5251	
AC	0.013	1	0.013	6.17	0.0230	
BC	1.225E-003	1	1.225E-003	0.57	0.4593	
A2	0.056	1	0.056	25.91	< 0.0001	
B2	0.016	1	0.016	7.48	0.0136	
C2	1.701E-003	1	1.701E-003	0.79	0.3847	
Residual	0.039	18	2.143E-003			
Lack of Fit	0.020	5	3.993E-003	2.79	0.0631	not significant
Pure Error	0.019	13	1.431E-003			
Cor Total	0.52	27				

Table II shows that speed (A), feed rate (B) and two-level interaction effect of speed and depth of cut (BC) and A2, B2 have significant effect on the surface roughness. But the effect of feed rate (B) is the most significant factor associated with surface roughness. This is anticipated as it is well known that for a given tool nose radius, the theoretical surface roughness ($R_a = f \sqrt{2/(32 \times r_e)}$) is mainly a function of the feed rate (Shaw, 1984). The Model F value of 24.88 implies the model is significant. There is only a 0.01% chance that a "Model F-Value" this large could occur due to noise. Values of "Prob > F" less than 0.0500

indicate model terms are significant. In this case A, B, AC, A2, B2 are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. If there are many insignificant model terms (not counting those required to support hierarchy Model reduction may improve our model. The "Lack of Fit F-value" of 2.79 implies there is a 6.31% chance that a "Lack of Fit F-value" this large could occur due to noise. Lack of fit is bad -- we want the model to fit.

Table 5.3 - Various R2 statistics for Surface Roughness

Std. Dev.	0.046	R-Squared	0.9256
Mean	0.79	Adj R-Squared	0.8884
C.V.%	5.88	Pred R-Squared	0.7845
PRESS	0.11	Adeq Precision	14.782

The "Pred R-Squared" of 0.7845 is in reasonable agreement with the "Adj R-Squared" of 0.8884. "Adeq Precision" measures the signal to noise ratio. A ratio greater than 4 is desirable. Ratio of 14.782 indicates an adequate signal.

Final Equation in Terms of Actual Factors:

$$R_a = 1.70386 - 0.037551 \text{ Speed} - 5.45880 \text{ Feed} + 8.27622 \text{ DOC} - (6.00000E-003) \text{ Speed} \times \text{Feed} +$$

$$0.046 \text{ Speed} \times \text{DOC} - 7.00 \text{ Feed} \times \text{DOC} + 2.24673E-004 \text{ Speed}^2 + 30.16822 \text{ Feed}^2 - 9.32710 \text{ DOC}^2$$

There are many insignificant terms in the equation and it can also be deduced from ANOVA table. Hence removing the insignificant terms and again analyzing ANOVA table we get,

Table 5.4 - ANOVA for Response Surface Reduced Quadratic Model

Source	Sum of Squares	df	MEAN SQUARE	F VALUE	p-value Prob > F	
Model	0.48	6	0.079	39.30	< 0.0001	Significant
A-Speed	0.011	1	0.011	5.57	0.0280	
B-Feed	0.23	1	0.23	114.53	< 0.0001	
C-DOC	8.022E-003	1	8.022E-003	3.97	0.0594	
AC	0.013	1	0.013	6.55	0.0183	
A2	0.057	1	0.057	28.45	< 0.0001	
B2	0.014	1	0.014	7.16	0.0142	
Residual	0.042	21	2.019E-003			
Lack of Fit	0.024	5	2.974E-003	2.08	0.1159	Not significant
Pure Error	0.019	13	1.431E-003			
Cor Total	0.52	27				

Table 5.5 - Various R2 statistics for Surface Roughness for Reduced Quadratic Model

Std. Dev.	0.045	R-Squared	0.9182
Mean	0.79	Adj R-Squared	0.8949
C.V.%	5.71	Pred R-Squared	0.8305
PRESS	0.088	Adeq Precision	19.227

The various R2 statistics (i.e. R2, adjusted R2 (R2 adj) and predicted R2 (R2 pred)) of the surface roughness are given in Table 5.5. The value of R2 = 0.9182 for surface roughness indicates that 91.82 % of the total variations are explained by the model. The adjusted R2 is a statistic that is adjusted for the "size"

of the model; that is, the number of factors (terms). The value of the R2 adj = 0.8949 indicates that 89.49 % of the total variability is explained by the model after considering the significant factors. R2 pred = 0.8305 is in good agreement with the R2 adj and shows that the model would be expected to explain

83.05% of the variability in new data (Montgomery, 2001). 'C.V.' stands for the coefficient of variation of the model and it is the error expressed as a percentage of the mean $((S.D./Mean) \times 100)$. Lower value of the coefficient of variation (C.V. = 5.71%) indicates improved precision and reliability of the conducted experiments.

Final Equation in Terms of Actual Factors:

$$\text{Surface Roughness (Ra)} = 2.33372 - 0.036045 \times \text{Speed} - 5.58070 \times \text{Feed} - 2.60556 \times \text{DOC} + 0.046 \text{Speed} \times \text{DOC} + 2.08632E-004 \text{Speed}^2 + 26.15789 \times \text{Feed}^2$$

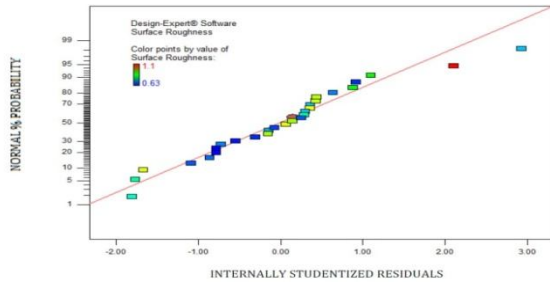


Fig. 5.0 NORMAL PLOT OF RESIDUALS:

Fig. 5.0 the normal probability plot of the residuals (i.e. error = predicted value from model – actual Value) for surface roughness is shown in Fig. 5.0, Fig. 5.0 reveals that the residuals lie Reasonably close to a straight line, giving support that terms mentioned in the model are the only significant (Montgomery, 2001).

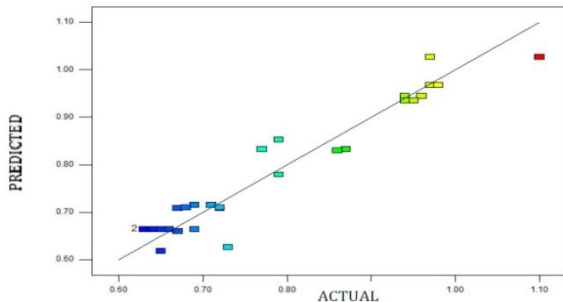


Fig. 5.1 PREDICTED Vs ACTUAL:

Fig. 5.1: Shows the actual values i.e. obtained through experimentation and the predicted valued i.e. values obtained from the model made for the surface roughness.

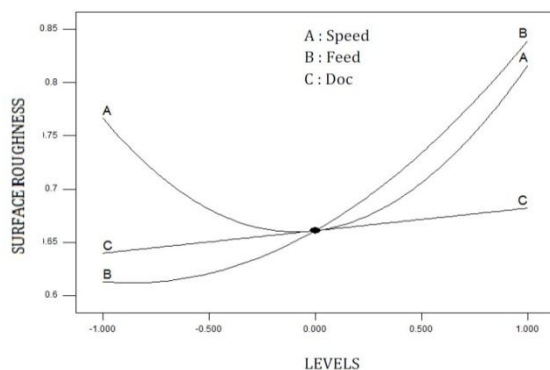


Fig. 5.2 PERTURBATIONS:

Fig 5.2 shows the variation of surface roughness with speed, feed and depth of cut. It can be observed from the fig that increasing depth of cut increases the surface roughness marginally and it can be considered not affecting surface roughness for this range. It can also be seen from the graph that surface roughness decreases with increase in cutting speed upto a certain point then further increase in cutting speed leads to increase in surface roughness. Increasing feed increases the surface roughness, this is anticipated as it is well known that for a given tool nose radius, the theoretical surface roughness $(Ra = f^2 / (32 \times re))$ is mainly a function of the feed rate (Shaw, 1984).

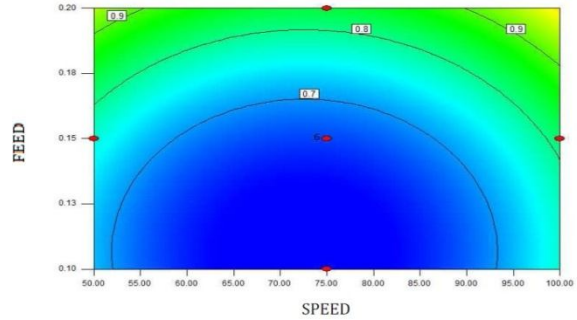


Fig. 5.3 CONTOUR:

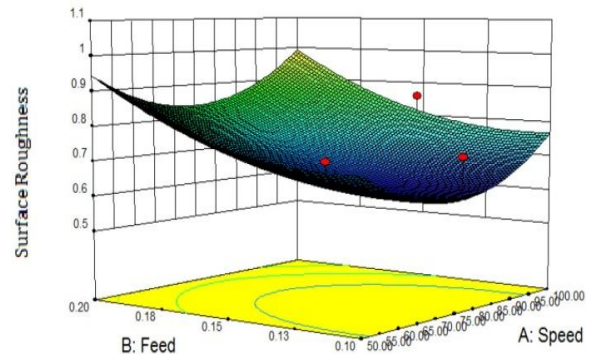


Fig. 5.4 3D SURFACE:

Figure 5.4 - Surface roughness 3D surface in cutting speed and feed rate plane at depth of cut of 0.1mm

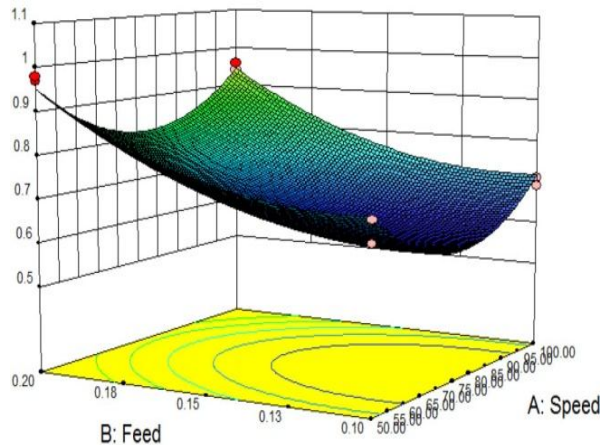


Figure 5.5 - Surface roughness 3D surface in cutting speed and feed rate plane at depth of cut of 0.125mm

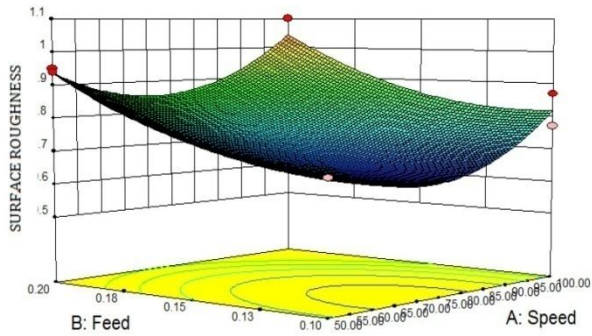


Figure 5.6 - Surface roughness 3D surface in cutting speed and feed rate plane at depth of cut of 0.150mm

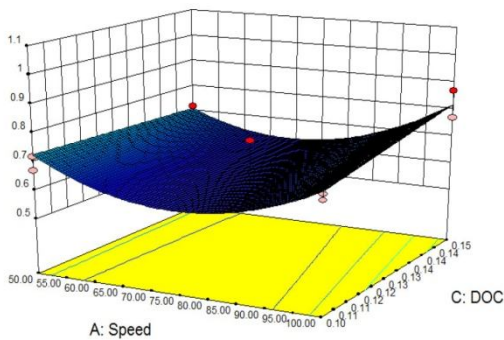


Figure 5.7 - Surface roughness 3D surface in cutting speed and depth of cut plane at feed of 0.01 mm/rev

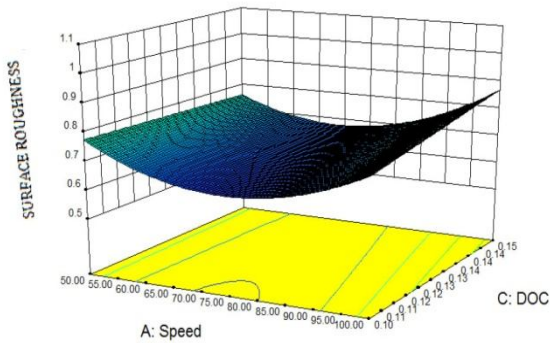


Figure 5.8 - Surface roughness 3D surface in cutting speed and depth of cut plane at feed of 0.015 mm/rev

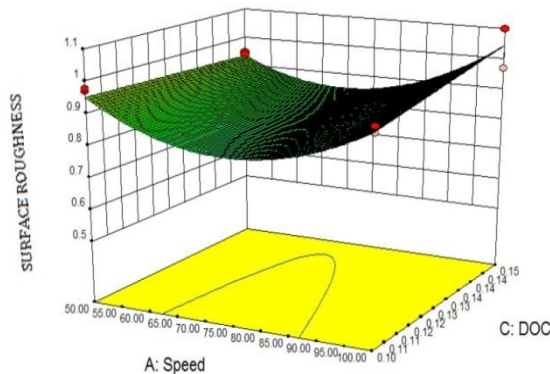


Figure 5.9 - Surface roughness 3D surface in cutting speed and depth of cut plane at feed of 0.02 mm/rev

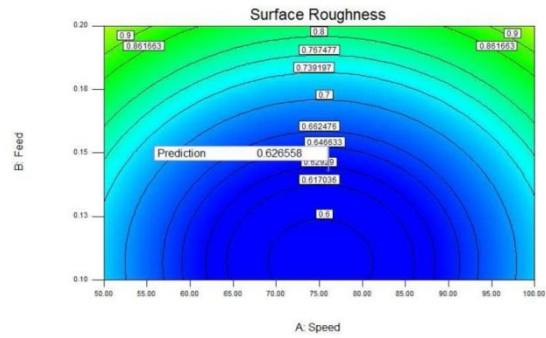


Figure 5.10- Optimization contour highlighting optimized (lowest) value of surface roughness at a Particular setting.

Figure 5.4, 5.5, 5.6 shows the Surface roughness in 3D surface in cutting speed and feed rate plane at three depth of cuts (0.100, 0.125, 0.150 mm) respectively. All have curvilinear profile in accordance to the quadratic model fitted. It can clearly be seen that surface roughness is increasing with increase in the feed rate and it varies with cutting speed, first decreases then increases as discussed before.

Figure 5.7, 5.8, 5.9 - shows the Surface roughness in 3D surface in cutting speed and depth of cut plane at three feed rates (0.10, 0.15, 0.2 mm/rev) respectively. It can clearly be seen that surface roughness does not vary much with the increase in depth of cut.

Figure 5.10 - Shows the optimization contour for surface roughness in feed and cutting speed plane. The figure shows the predicted optimized value (minimum value) of surface roughness which can be obtained in the given sets of feed, speed, depths of cut. The solution obtained through the Design Expert software is shown below. At this set of speed, feed and depth of cut one can get the lowest value of surface Roughness.

Table 5.7- Solution:

Surface Roughness	0.626558 μm
Feed	0.14mm/rev
DOC	0.102 mm
Speed	76.10 m/min

Thus the minimum value of roughness that can be achieved in given ranges of parameter values is 0.626558 μm , which is obtained when feed is approximately at medium level (0.15mm/rev), depth of cut is near to lower level (0.10mm) and speed is also at medium level (75m/min).

SCOPE FOR FUTURE WORK:

- One of the important facts is whether the system contains a maximum or a minimum or a saddle point, which has a wide interest in industry. Therefore, RSM is being increasingly used in the industry. Also, in recent years more emphasis has

been placed by the chemical and processing field for finding regions where there is an improvement in response instead of finding the optimum response (Myers, Khuri, and Carter). In result, application and development of RSM will continue to be used in many areas in the future.

- Since C-263 is a High temperature material it is always in use of aircrafts and industrial gas turbines. It can be used in space industry, where temperature goes on high counts. An adjustment in composition is still a very important way to improve the properties.

CONCLUSION:

This project presents the findings of an experimental investigation of the effect of cutting speed, feed rate and depth of cut on the surface roughness in turning of Nicrofer C-263 alloy using PVD TiAlN coated carbide tool and following conclusions are drawn. Quadratic model is fitted for surface roughness. The results show that the surface roughness does not vary much with experimental depth of cut in the range of 0.1 to 0.15 mm. A quadratic model best fits the variation of surface roughness with feed rate, speed and depth of cut. Feed rate is the dominant contributor, accounting for 69.06% of the variation in surface roughness whereas cutting speed accounts for 3.30% and depth of cut 2.41%. Secondary contributions of interaction effect between speed and depth of cut (3.90%), second order (quadratic) effect

of cutting speed (17.11%) and feed (4.2 %). Good surface finish can be achieved when depth of cut is set nearer to lower level of the experimental range (0.1mm), feed rate at mid level of the experimental range (0.15mm/rev) and cutting speed also at mid level of experiment range (75 m/min). Contour plots can be used for selecting the cutting parameters for providing the given desired surface roughness. The values of feed, speed, depth of cut has been found for best surface finish (lowest surface roughness). These are 0.14 mm/rev .76.10 m/min and 0.102 mm respectively. The value of surface roughness at these setting is predicted as 0.626558 μm .

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ANALYSIS OF SURFACE ROUGHNESS AND MATERIAL REMOVAL RATE (MRR) IN TURNING OPERATION OF SUPER ALLOY NIMONIC 75

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Abstract:-The objective of the present work is to analyse the surface roughness and material removal rate(MRR) in turning operation of super alloy NIMONIC 75 so that the quality of machined parts can be optimized. The working ranges and levels of the machining process (turning) parameters are found using three factors. Cutting speed (V_c - m/min), feed rate (f - mm/rev) and depth of cut (d - mm). The Design-Expert software has been used to investigate the effects of the Machining process parameters and subsequently to predict sets of optimal parameters for optimum quality characteristics. The response surface methodology (RSM) in conjunction with second order central composite rotatable design has been used to develop the empirical models for response characteristics. Desirability functions have been used for simultaneous optimization of performance measures. Also, the ANOVA technique and utility function have been used for response optimization. Confirmation experiments are further conducted to validate the results.

Keywords: Cutting parameters; turning process; feed force; RSM(Response Surface Methodology); ANOVA; Nimonic 75, TiAlN coated carbide tool, DOE(Design Expert Software v 8),

INTRODUCTION:

Significant advances have been made in understanding the behaviour of engineering materials when machining at higher cutting conditions from practical and theoretical standpoints. This approach has enabled the aerospace industry to cope with constant introduction of new materials that allow the engine temperature to increase at a rate of 100C per annum since the 1950s. Improvements achieved from research and development activities in this area have particularly enhanced the machining of difficult-to-cut nickel base and titanium alloys that have traditionally exhibited low machinability due to their peculiar characteristics such as poor thermal conductivity, high strength at elevated temperature, resistance to wear and chemical degradation, etc. A good understanding of the cutting tool materials, cutting conditions, processing time and functionality of the machined component will lead to efficient and economic machining of nickel and titanium base superalloys. Rather than just setting a very low feed rate to assure a low surface roughness, for example, an experimental method might determine that a faster feed rate, in combination with other parameter settings, would produce the desired surface roughness.

LITERATURE REVIEW

1. M.Y. Noordin, Y.C. Tang and D. Kurniawan et al. 2007 observed that the introduction of hard turning has provided an alternative to the conventional processing technology used to manufacture parts made from hardened steels. Shorter product development time along with being more environmentally friendly are among

the benefits offered by hard turning, which potentially results in lower manufacturing cost per part. However, common tool materials for hard turning applications are expensive. Due to the continuous developments in cutting tool materials and coating technology, inexpensive coated carbide cutting tools are being investigated to determine the potential of using them for use in extreme conditions as in hard turning. TiAlN coated carbide tool was selected to finish machine hardened steel. Performing hard turning dry at various cutting conditions, that is, cutting speed and feed rate, revealed that satisfactory tool life values and surface finish values that meet the strict range of finish machining were obtained when finish machining hardened steel of 47-48 HRC hardness.

2. Yen et al. (2004) studied the effects of edge preparation of the cutting tool (round/hone edge and T- land/chamfer edge) on cutting forces using finite element analysis in orthogonal machining. Jawahir et al. (1992) carried out experimental studies on finish turning of low and medium carbon steel (AISI1018 and 1045) with cermet tool for investigating machinability parameters such as chip breakability, surface roughness and specific cutting pressure.

EXPERIMENTAL PROCEDURE:

- 1) Since depth of cut has least significance on surface roughness so there were no preliminary tests were performed on depth of cut.
- 2) Selection of speed and feed were taken by preliminary pilot experiments.

Table below shows results for pilot experiments:

5.2.2 Preliminary Experiments for Feed

S.No.	Speed	Feed	DOC	R _{a1}	R _{a2}	R _{avg}
1.	175	0.015	0.15	0.24	0.21	0.23
2.	175	0.02	0.15	0.19	0.26	0.24
3.	175	0.025	0.15	0.27	0.31	0.29
4.	175	0.03	0.15	0.25	0.37	0.31
5.	175	0.035	0.15	0.54	0.47	0.51
6.	175	0.04	0.15	0.83	0.69	0.76

S.No.	Speed	Feed	DOC	R _{a1}	R _{a2}	R _{avg}
1.	50	0.02	0.15	0.51	0.65	0.58
2.	100	0.02	0.15	0.39	0.46	0.43
3.	150	0.02	0.15	0.23	0.19	0.22
4.	200	0.02	0.15	0.17	0.24	0.21
5.	250	0.02	0.15	0.43	0.49	0.46

- After finding levels of parameters, design matrix as shown in table 5.3 was prepared with the help of Design Expert V 8.0 software.
- Experiments were done as per the design matrix. The surface roughness was measured after each trial with the help of handysurf and all the data was recorded.

Table below shows Design Matrix with Responses using DOE software:

Standard Order	Run Order	Speed m/min	Feed mm/rev	DOC mm	R _{a1} micro	R _{a2} micro	R _{avg} micro	MRR ₁ mm ³ /min	MRR ₂ mm ³ /min	MRR _{avg} mm ³ /min
1.	18	100	0.02	0.1	0.35	0.40	0.375	199.38	199.36	199.37
2.	20	100	0.02	0.1	0.33	0.25	0.29	199.37	199.38	199.38
3.	9	250	0.02	0.1	0.43	0.38	0.405	498.45	498.45	498.45
4.	12	250	0.02	0.1	0.20	0.32	0.26	498.54	498.37	498.46
5.	8	100	0.04	0.1	0.68	0.76	0.72	398.78	398.77	398.78
6.	19	100	0.04	0.1	0.37	0.60	0.495	398.74	398.72	398.73
7.	1	250	0.04	0.1	0.50	0.65	0.575	996.95	996.86	996.91
8.	10	250	0.04	0.1	0.28	0.70	0.49	996.95	996.87	996.91
9.	17	100	0.02	0.15	0.36	0.30	0.33	298.62	298.58	298.60
10.	13	100	0.02	0.15	0.31	0.26	0.285	298.58	298.59	298.59
11.	5	250	0.02	0.15	0.39	0.43	0.41	746.63	746.43	746.53
12.	15	250	0.02	0.15	0.23	0.57	0.40	746.58	746.31	746.45
13.	2	100	0.04	0.15	0.70	1.00	0.85	597.20	597.14	597.17
14.	16	100	0.04	0.15	0.73	0.83	0.78	597.31	597.20	597.26
15.	14	250	0.04	0.15	0.76	0.73	0.745	1493.14	1492.95	1493.05
16.	6	250	0.04	0.15	0.66	0.79	0.725	1493.22	1492.99	1493.11
17.	3	175	0.03	0.125	0.26	0.46	0.36	653.82	653.84	653.73
18.	7	175	0.03	0.125	0.44	0.22	0.33	653.68	653.70	653.69
19.	4	175	0.03	0.125	0.20	0.24	0.22	653.74	653.67	653.71
20.	11	175	0.03	0.125	0.20	0.27	0.235	653.73	653.60	653.67
21.	28	100	0.03	0.125	0.41	0.47	0.44	373.58	373.48	373.53
22.	23	250	0.03	0.125	0.43	0.49	0.46	933.88	933.81	933.85
23.	27	175	0.02	0.125	0.15	0.26	0.205	435.81	435.74	435.78

The data tabulated in the table 5.4 is analyzed with Design Expert V8.0 software. The analysis is shown and discussed here.

Table 5.4: Model Summary Statistics for surface roughness.

	Sequential	Lack of Fit	Adjusted	Predicted	
Source	p-value	p-value	R-Squared	R-Squared	
Linear	<0.0001	0.0084	0.5959	0.5056	
2FI	0.3207	0.0073	0.6083	0.4847	
Quadratic	0.0008	0.2564	0.8229	0.6629	Suggested
Cubic	0.3930	0.1332	0.8274	-1.5856	Aliased

Table 5.8 shows that quadratic model has to be applied for the observed sets of reading of surface roughness. It clearly shows that the quadratic model

is the best suggested model for surface roughness with larger R2 statistics value.

Table 5.8 below shows the ANOVA analysis for Response Surface Quadratic model

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Block	0.014	1	0.014			
Model	0.80	9	0.89	14.42	<0.0001	Significant
A-Speed	4.014E-004	1	4.014E-004	0.065	0.8020	
B-Feed	0.54	1	0.54	87.15	<0.0001	
C-DOC	0.044	1	0.044	7.11	0.0162	
AB	0.015	1	0.015	2.48	0.1340	
AC	1.914E-003	1	1.914E-003	0.31	0.5853	
BC	0.034	1	0.034	5.46	0.0320	
A ₂	0.034	1	0.034	5.48	0.0316	
B ₂	0.037	1	0.037	5.99	0.0256	
C ₂	1.208E-003	1	1.208E-003	0.20	0.6641	
Residual	0.11	17	6.186E-003			
Lack of fit	0.041	5	8.143E-003	1.52	0.2564	Not significant
Pure error	0.064	12	5.370E-003			
Cor Total	0.92	27				
Std. Dev: 0.078649		C.V. %: 17.50545		Adj R-Squared: 0.822884		
Mean: 0.449286		R-Squared: 0.884193		Pred R-Squared: 0.662933		

The Model F-value of 14.42 implies the model is significant. There is only a 0.01% chance that "Model F-Value" this large could occur due to noise.

- Values of "Prob > F" less than 0.0500 indicate model terms are significant. In this case B,C, BC, A₂, B₂ are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. If there are many insignificant model terms (not counting those required to support hierarchy), model reduction may improve your model.
- The "Lack of Fit F-value" of 1.52 implies the Lack of Fit is not significant relative to the pure error. There is a 25.64% chance that a "Lack of Fit F-value" this large could occur due to noise. Non-significant lack of fit is good -- we want the model to fit.
- The various R2 statistics (i.e. R2, adjusted R2 (R2adj) and predicted R² (R²pred)) of the surface roughness are given in Table 5.8. The value of R2 = 0.884193 for surface roughness indicates that 88.41% of the total variations are explained by the model.
- The adjusted R2 is a statistic that is adjusted for the "size" of the model; that is, the number of factors (terms). The value of the R2adj = 0.822884 indicates that 82.28% of the total variability is explained by the model after considering the significant factors.

Final Equation in Terms of Actual Factors:

$$\begin{aligned}
 \text{Surface Roughness} = & +1.30374 - (6.49994E-00 * \text{Speed}) - (68.32068 * \text{Feed}) + (3.86029 * \text{DOC}) - \\
 & (0.04125 * \text{Speed} * \text{Feed}) + (5.83333E-003 * \text{Speed} * \text{DOC}) + (183.75000 * \text{Feed} * \text{DOC}) \\
 & + (1.98152E-005 * \text{Speed}^2) + (1164.60396 * \text{Feed}^2) - (33.66337 * \text{DOC}^2) \\
 & \dots (5.1)
 \end{aligned}$$

There are many insignificant terms in the equation and it can also be deduced from ANOVA table.

Hence removing the insignificant terms and again analyzing ANOVA table we get:

Table 5.9 below shows the Reduced or Pooled ANOVA table for surface roughness after excluding insignificant terms i.e. A, AB, AC, C²

Table 5.9: ANOVA for Response Surface Reduced Quadratic Model (Surface roughness)						
Source	Sum of Squares	df	Mean Square	F-Value	p-value Prob > F	
Block	0.014	1	0.014			
Model	0.78	5	0.16	26.56	< 0.0001	Significant
B-Feed	0.54	1	0.54	91.30	< 0.0001	
C-DOC	0.044	1	0.044	7.45	0.0125	
BC	0.034	1	0.034	5.72	0.0262	
A ²	0.034	1	0.034	5.74	0.0259	
B ²	0.037	1	0.037	6.31	0.0202	
Residual	0.12	21	5.905E-003			
Lack of Fit	0.060	9	6.617E-003	1.23	0.3601	Not significant
Pure Error	0.064	12	5.370E-003			
Cor Total	0.92	27				
Std. Dev: 0.079		C.V. %: 17.50		Adj R-Squared: 0.8231		
Mean: 0.45		R-Squared: 0.8639		Pred R-Squared: 0.7305		

Final Equation in Terms of Actual Factors:

$$\text{Surface Roughness} = +1.80482 - (6.52062E-003 * \text{Speed}) - (70.93346 * \text{Feed}) - (3.53472 * \text{DOC}) + (183.75 * \text{Feed} * \text{DOC}) + (1.84505E-005 * \text{Speed}^2) + (1087.83784 * \text{Feed}^2) \dots (5.2)$$

Equation 5.2 is based on final table 5.9

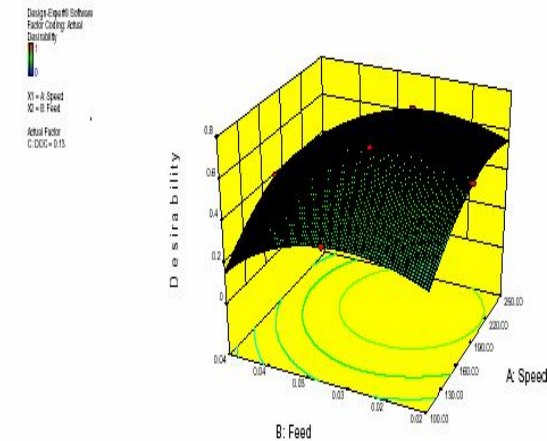


Figure 5.15: 3D Surface Graph of Desirability for speed and feed

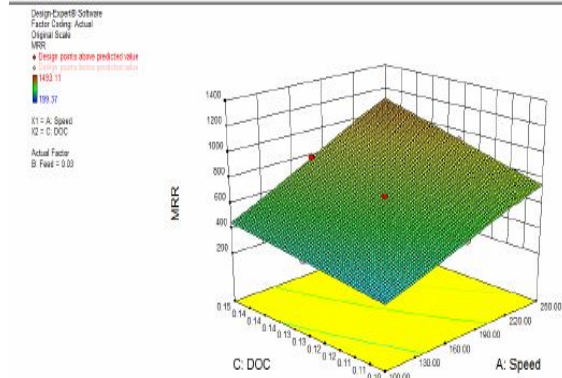
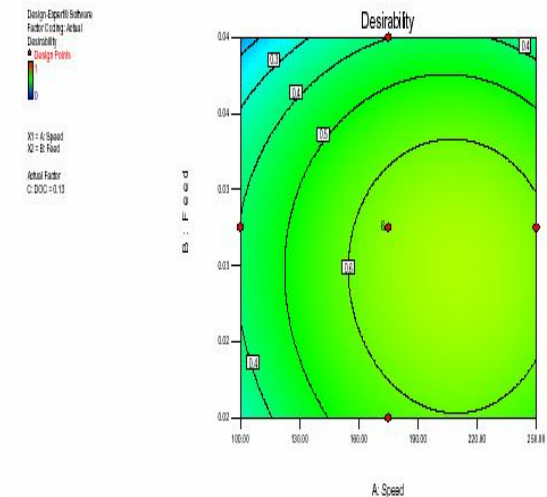


Figure 5.12: Response surface between Speed, DOC and MRR

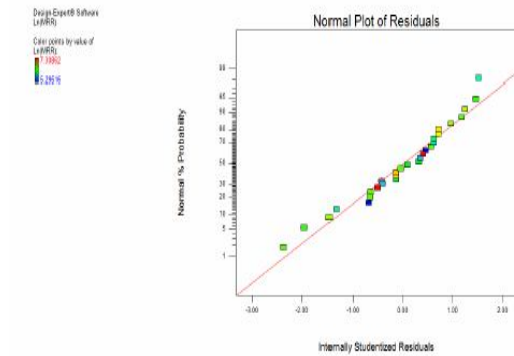


Figure 5.13: Normal Probability curve for MRR

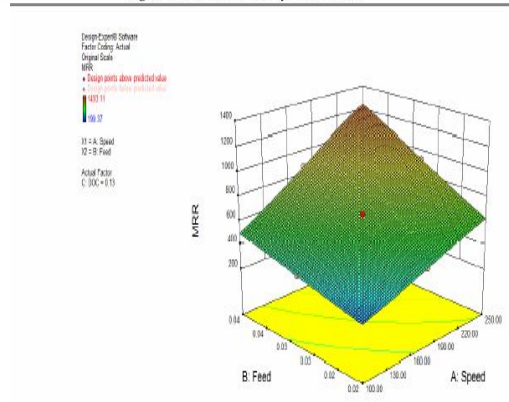


Figure 5.10: Response surface between Speed, Feed and MRR

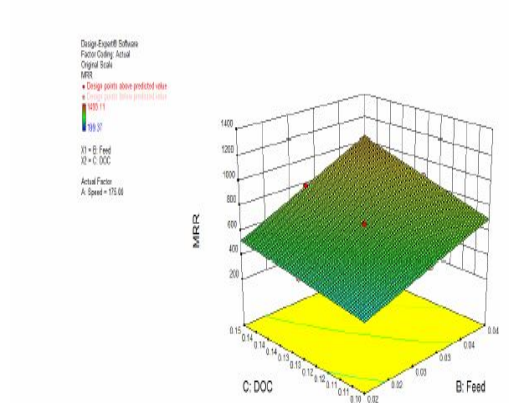


Figure 5.11: Response surface between DOC, Feed and MRR

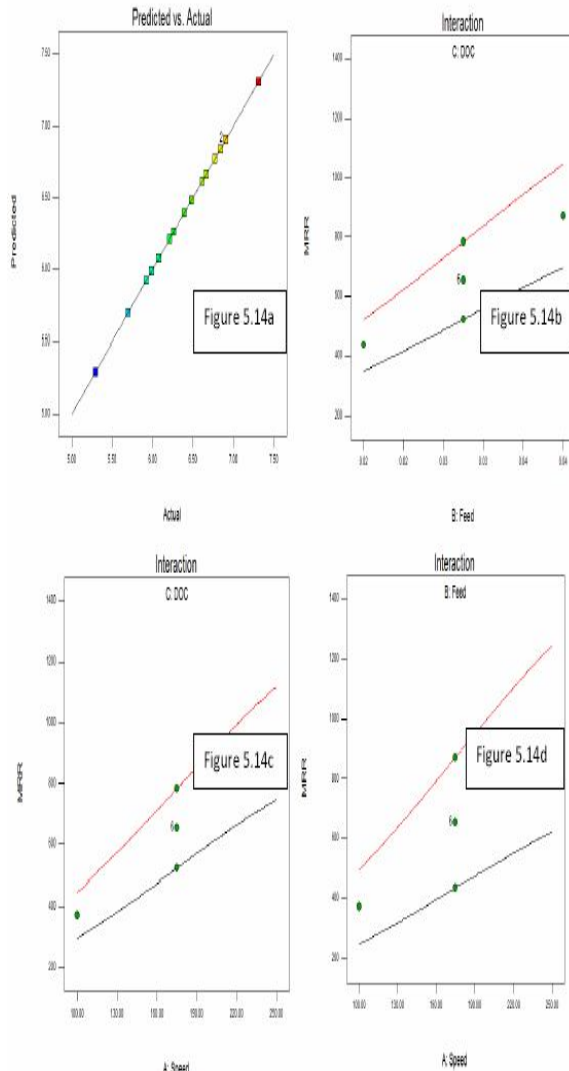


Figure 5.14: Actual v/s Predicted & Interaction curves

Table 5.7- Solution:

Feed	0.02 mm/rev
DOC	0.1mm
Speed	175 m/min

Above table shows the final result to achieve optimum surface finish in machining of nimonic 75.

SCOPE FOR FUTURE WORK:

- One of the important facts is whether the system contains a maximum or a minimum or a saddle point, which has a wide interest in industry. Therefore, RSM is being increasingly used in the industry. Also, in recent years more emphasis has been placed by the chemical and processing field for finding regions where there is an improvement in response instead of finding the optimum response (Myers, Khuri, and Carter). In result, application and development of RSM will continue to be used in many areas in the future.
- Since C-263 is a High temperature material it is always in use of aircrafts and industrial gas

turbines. It can be used in space industry, where temperature goes on high counts. An adjustment in composition is still a very important way to improve the properties.

CONCLUSION:

The surface roughness follows the quadratic trend in the given ranges of speed (100 to 250 m/min), feed (0.02 to 0.04 mm/rev) and depth of cut (0.1mm to 0.15mm). The material removal rate undergone natural log transformation and fitted to the quadratic model in the given range of parameters. Feed rate is the most significant parameter in judging the surface roughness. Feed rate is contributing 58.69% to the surface roughness. Optimum value of parameters to maximize the material removal rate is Cutting speed = 250 m/min, Feed = 0.04 mm/rev & Depth of cut = 0.15 mm Optimum value of parameters to minimize the value of surface roughness is Cutting speed = 175 m/min, Feed = 0.02 mm/rev & Depth of cut = 0.1mm. Optimum value of parameters to optimize the multiple responses by using desirability function on giving more importance to surface roughness (5 units) and less importance to MRR (2 units) is Cutting speed = 204 m/min, Feed = 0.03 mm/rev. and Depth of cut = 0.15 mm At higher speed (250 m/min), a lot of heat was generated which accelerated the tool wear rate. The coefficient of friction of PVD TiAlN coating is 0.35 and micro hardness is 2300-2500HV. But if some better coating with higher micro hardness and lower coefficient of friction is used then the tool life can be extended.

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ISSUES AND CHALLENGES OF SUPPLY CHAIN MANAGEMENT IN INDIA

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Abstract: Despite the extensive research carried out in the area of supply chain management (SCM) all over the world, SCM practices have not yet been well adopted in developing countries like India. This paper highlights the present issues and challenges of SCM in India. Supply chain management is the discipline of optimizing the delivery of goods, services and information from supplier to customer. An effective supply chain makes companies competitive and profitable. The best example from the global arena are the companies like Dell, Wal-Mart and Amazon etc. However some Indian companies are moving towards making their supply chain efficient, but most of them have done very little. If companies choose to compete in the global environment, they will have to look for ways to reduce expenditures of their suppliers and channel partners. This reduction in cost will lead the revamping of supply chains and significant investment in information technology, because Information Technology (IT) tools and techniques play very important role in the performance of the SCM.

Key words: *Supply Chain Management (SCM), Information Technology (IT) tools, cost reduction, issues and challenges in Supply Chain Management in India.*

1.0 INTRODUCTION

Supply chain Management (SCM) seems to be a growing area of interest amongst researchers and practitioners from varied disciplines. Supply chain (SC) has evolved from the era when related to materials flow (Forrester, 1961) were introduced, which later on become part of SCM. SC has evolved very rapidly since 1990s showing exponential growth. Generally SC consists of different functions: logistics, inventory, purchasing, and procurement, production, planning, intra-and inter-organizational relationships and performance measures. To improve the overall performance of SC the members of SC may behave as a part of a unified system and coordinate with each other. Some Indian companies are moving towards making their supply chain and logistics efficient, most of them have done very little or nothing. If companies choose to compete in the global environment, they will have to look for ways to reduce expenditures of their suppliers and channel partners, logistics or distribution partners. This reduction in cost will lead the revamping of supply chains and significant investment in information technology, because information technology tools and techniques plays very important role in the performance of the SCM.

This paper is organized as follows: Section 2 describes Literature Review, section three gives information about Information Technology (IT), IT tools and ITs importance on SCM, section four highlights the issues and challenges of SCM in India, section five gives the overcoming challenges and issues of SCM and section six presents conclusive remarks of SCM in Indian context.

1.1 SCM defined

The Council of Logistic Management (CLM) (2000) defines SCM as “*the systematic, strategic coordination of the traditional business functions and tactics across these business functions within a particular organization and across business within a supply chain for the purpose of improving the long term performance of the individual organizations and the supply chain as a whole*”.

2.0 LITERATURE SURVEY

The size of the Indian logistics market is estimated as US\$ 14.31 billion in 2004, US\$19.54 billion in 2009 and is expected to grow up in 2013. The logistic cost as percentage of the Gross Domestic Product (GDP) stood at 13% in India in 2004 (Confederation of Indian Industries(CII) results), in comparison to 11% in Europe and 9% in the U.S. often total logistic cost, transportation represents 39% while warehousing, packing and inventory accounts for 24% of the total costs. Higher logistic costs mainly due to poor infrastructural facilities in the country. The higher logistic costs represent high products /service costs in the international market. The logistic cost also influenced by constraints such as shortage in electricity and skilled labor, road, port congestion etc. Shipments by road that can be completed in three days in the US. For example, it could take as long as nine days in India. Ships in India can wait for five days to dock at an Indian port, compared to little or no wait time in Europe. Further, there are few logistic firms in India with fleet size larger than 100 trucks. Moreover, very few trucks are fitted with GPS tracking devices, thereby preventing any real time tracking shipments.

At the same time Indian organizations lag in supply chain performance. For example Pantaloon retail, a major Indian retailer, had inventory equivalent of about 100 day's sales from 2006 to 2009. Even after improvements made in 2010, their inventory levels fell only to about 77 days of sales. Yet this is still well above the inventory levels of leading retailers in developed economies. Wal-Mart, for example, has an inventory equivalent of only 29 days of sales in 2010 (Supply Chain Management Review, July 2012). Additionally many supply chain activities such as transportation, warehousing, and retail store replenishments remain very fragmented in India.

Now Indian organizations are looking for collaboration with supply chain partners to cope up with the increasing uncertainty of supply networks, globalization of business proliferation of product variety and shortening of product life cycles.

The recent technological advances in IT have made it possible to make supply chain lean and thin. Holistically speaking, without IT systems in place, no supply chain could be agile nor could adapt and align fast to the changing business needs.

3.0 IT TOOLS AND TECHNOLOGIES

Information is essential to making supply chain and logistic decisions, because IT provides the global scope needed to make optimal decisions. Best in class companies world wide have successfully used sophisticated IT systems to streamline process and enable effective decision making. The information necessary to achieve global scope, corresponding to the different stages of the supply chain as 1) supplier information 2) manufacturing information 3) distribution and retailing information and 4) demand information.

IT is used to improve inter organizational coordination (McAfee, 2002; Sanders 2008) and in turn, inter organizational coordination has been shown to have a positive impact on select firm performance measures such as customer service, lead time and production costs.

IT helps to link the point of production seamlessly with the point of delivery or purchase. IT allows planning, tracking and estimating the lead time based on the real data, advances in IT (eg. Internet, electronic data interchange, ERP, E-business and many more) enable firms to rapidly exchange products, information, and funds and utilize collaborative methods to optimize SC operations.

Internet and web can enhance effective communication, which helps members of SC review past performance, monitor current performance and predict when and how much certain products need to be produced and to manage workflow systems (Liu et al 2005)

3.1 Supply Chain Coordination: The supply chain members perform different functions or activities like logistics, inventory management. Ordering forecasting and product design involved in management of flow of goods, information and money. In traditional supply chain, individual members of SC have been performing these activities independently. The SC members may earn benefits by coordinating various activities (Arshinder, Kanda, A., Deshmukh, S.G., 2008). The lack of coordination may result in poor performance of supply chain. Fisher et al. 1994 has cited a study of the US food industry, which estimated that poor coordination among SC partners was wasting \$30 billion annually. The mismatch between supply and demand results in rise in the cost of stock out, markdown, expediting, transshipment, advertising and sale preparation, excess inventory.

Coordination can be visualized in different functions such as logistics, inventory management, forecasting, transportation etc. Manufacturers and retailers etc can effectively managed using coordination.

3.2 Collaborative Planning Forecasting and Replenishment (CPFR)

CPFR model was developed by SCOR (Supply Chain Organization) and "at its essence, CPFR is a set of business processes that helps eliminate demand and supply uncertainty through improved communication between supply chain trading partners" (Larsen et al. 2003). CPFR is a model to develop collaboration and this to happen there should be a complete integration between manufacturer, their suppliers, shipper, and logistics partner. The primary benefit of integration is that all business units and supply chain partners share the same data, synchronize action and minimize distortions and bullwhip effect in demand management". This integration would require technology platforms such as ERP, SRM or CRM platforms or legacy systems connected through web service.

3.3 Enterprise Resource Planning (ERP)

ERP provides the transactional tracking and global visibility of information from any part of a company and its supply chain that allows intelligent decisions to be made. This real time information helps a supply chain to improve the quality of its operational decisions. This ERP software has been successful in improving data integrity within the supply chain.

3.4 Customers Relations Management (CRM)

In the changing Global environment, increasing customer satisfaction is one of key success factors in all industries so also in supply chain management. So it is very much essential to make all policies keeping in view customer and availability of technology. In traditional method of CRM, phone, paper, personal interaction etc are used for communication and relationship. But with IT enabled SCM with CRM

software can store customer details, while making transactions with the customer monitors buying and behavior of decision of different customers minimize internal fault, help in the automation process, automatic tracking and response, bill finalization and analysis of communication pattern.

3.5 Supplier Relation Management (SRM)

Supplier Relation Management is to streamline and make more effective the process between an enterprise and supplier. SRM includes both business practices and software and is a part of the information flow component of SCM. According to the proponents, the use of SRM software leads to lower production costs, higher quality but lower priced end product.

3.6 Electronic Supply Chain (E-Supply Chain)

With the quick development of Electronic commerce, SCM can be made more effective through electronic means. For instance through web site each member in the chain can access the shared database. E-Supply chains can be designed and studied through a systematic approach, which considers the various levels at which information technology can be applied in a traditional supply chains.

3.7 Integrated supply chain network

An integrated supply chain network is a group of independent companies, often located in different countries, forming a strategic alliance with the common goal of designing, manufacturing, and delivering right-quality products to customer groups faster than other alliance groups and vertically integrated firms. The structure of an integrated supply chain network held together by a logistics and information network is shown in Figure. Such an integrated supply chain provides the basis for application of various information technologies that transformed it into e-supply chains.

3.8 Bar coding: Barcodes have influenced almost every aspect of supply chain management. The use of barcodes makes business integration process in SCM simpler and more efficient. Barcodes are an effective identification tool that helps track products and greatly reduce errors. Barcode technology has a range of advantages such as being a affordable, easy to handle and accurate. These advantages make barcodes widely used in SCM and accepted across world. Employing barcode technology in inventory practices enable timely and accurate information that helps to operate with greater warehouse efficiency and lower inventory on hand. Using barcodes along with the Just In Time(JIT) inventory method allows companies to estimate precisely when run out of stock dependency on huge buffer stocks.

3.9 Radio Frequency Identification (RFID)

Radio Frequency Identification is a type of automatic identification system. The purpose of RFID system is to enable data to be transmitted by a portable device called tag, which is read by RFID reader and processed according to the needs of a particular application. The data transmitted by the tag provides identification or location information or specifies about the product tagged, such as price, color date of purchase etc.

Wal-Mart has successfully tested the technology with the top 100 suppliers, it is now taking steps to expand roll out of the new technology across other suppliers and stores.

In India very few companies are implementing this technology. Because of the high cost of implementation of the system, most of the Indian companies are not in favour of RFID technology. This high cost is associated with retooling, extensive partner relationship across channel members particularly, manufacturers and retailers. In future, with a prospect of cost effectiveness, RFID may be put to use extensively.

3.10 Web Services

Not all companies can afford to deploy the recent ERP, SRM, CRM and other software modules as these are expensive and because replacing the legacy ones entail huge cost and effort. However, it is necessary to integrate the old traditional system with the company and supplier and other channel partners. The web services do exactly that to integrate the old legacy system with one another thus saves cost on the deployment of the costly new IT systems.

4. SUPPLY CHAIN MANAGEMENT ISSUES AND CHALLENGES IN INDIA

4.1 High cost of logistics.

Logistic cost is 13% of India's GDP in comparison to 11% in Europe and 9% in the U.S. of the total logistic cost, transportation represents 39%, while warehousing, packing and inventory accounts 24% of the total costs(365businessdays.com). Higher logistic costs are mainly due to poor infrastructure facilities in the country.

4.2 Physical infrastructure –a bottleneck

Insufficient distribution channels and infrastructure bottlenecks restrict the scope to reach consumer of products nationwide. Though the country has developed the largest road networks in the world, yet the regional concentration of manufacturing in Indian but geographically diversified distribution activities as well as infrastructure bottlenecks, e – infrastructural facility is not comparable to developed countries. Less than half of the roads were paved in India and less than 2000Km were express highways in 2007, which was significantly lower than china's 30,000Km (365businessdays.com). The scarcity of

tracking technologies like global positioning systems (GPS),(www.scmr.com) the inability of ports to handle goods quickly, and the lack of modern technology in warehouse. Though there are considerable investment underway to address these issue, such as projects take large amount of time in India by comparison, emerging economic countries like china and brazil have been able to complete infrastructural projects on a considerably shorter timeline.

4.3 The low acceptance of integrated Third party logistics (3PL)

Apart from the infrastructural challenges, business in India doesn't have the access to the best supply chain services for a variety of reasons. The low acceptance of integrated third party logistics (3PL) firms in India is one part of the problem. The cost differential between the integrated 3PL an existing transport firms is wide. So shippers find it difficult to justify the additional cost of a 3PL, even though they would be receiving high technology support and generally superior service from such provider. Further, the infrastructural challenge mentioned above constrains the internationally known 3PLs from operating with the same speed and efficiency as they do in developed economies.

4.4 Cost of quality service

According to industry analysts, logistic costs in India are among the world's highest. Outside of the metros and few cities the delivery time is very uncertain.

4.5 Technology usage and inadequate investments in IT

Technology usage is very low in India, which restricts the scope of increasing productivity and efficiency (365businessdays.com). Though India is a leading exporter of IT products, Indian companies are unfortunately least inclined to use them. Hence, the IT penetration in India is low. This is not surprising that Indian companies are 1.3% of the gross sales. For companies that use IT systems, there seem to be a clear bias towards using stand-alone IT systems. Using these systems would mean that collaboration would be low as these stand-alone systems are not friendly when it comes to implementing recent supply chain models like CPFR, VMI etc. in the present scenario the supply chain around the world is On-Demand, using technology such as internet, mobile, wireless, RFID etc, whereas Indian supply chain is still to come out of this slumber.

5. IMPROVING THE SUPPLY CHAIN CAPABILITIES IN INDIA

5.1 *Carefully analyze the infrastructure:* it is important to consider infrastructural issues such as high ways, and access to ports and supporting the information technology.

5.2 Investment in IT

If the Indian companies are to adopt global supply chain standards and benchmarks against the global companies there is a long way ahead. In addition, this way starts with investment in information technology. This investment will go towards making companies connect with suppliers and partners. This connectivity will improve the visibility in the chain and thus collaboration can take place with partners. This collaboration will make the supply chain agile and align itself to the changing market demand.

5.2 Leverage IT Capabilities

The IT talent is not hard to find in India and Indian companies can use it to their advantage. They can employ trained IT engineers at lower cost as compared to the counterparts in other countries and thus become competitive.

5.3 Align Supply Chain Strategy with Business Strategy

So far, Indian companies have marketing, personnel, accounts and other departments but no supply chain department to speak of little. Purchase or procurement section has more or less carried out the supply chain and logistic functions. These departments however are not aligned to follow supply chain as a strategic area and are often not in harmony with other departments or with partners. Now the time is ripe to align competitive advantage, increase profitability, and market share in these challenging times.

5.5 Potential savings for India –

Is possible if logistic costs decreases by 1%, approximately \$4.8 billion per year as Indian GDP is 480 billions(Indian logistic cost per GDP is 13%)(365businessdays.com).

6.0 CONCLUSIONS:

India is one of the world's fastest growing economies with diverse markets. Managing supply chain in such a vast country is most challenging for any organization because of business practices, government regulations, technology capabilities, transportation infrastructures etc. the current paper has explored the state and issues of supply chain management of India. To achieve an improved performance, Indian organizations should focus on applying techniques which offer a strategic opportunity for companies to gain an increase in revenue. This is possible by improving the infrastructural development and refocusing on integrating IT with supply chain management and Logistics. Organizations must realize that they must harness the power of IT to collaborate with their business alliances.

Research methodology: The research is based on secondary data, which includes compilation of research articles of the experts in the field and reflection of the various books on supply chain management. The approach is exploratory in nature.

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DESIGN AND IMPLEMENTATION OF CNC CARVING MACHINE (USING: MCX314) CNC MACHINE

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Abstract-According to the character of carving machine motion control the motion controller with 3-axis Simultaneous-motioned is achieved. MCX314 is selected as motor driving chip of numerical control device, and ARM7 as central processing unit of controller. The working principle of hardware circuit with CPU of AT91FR40162 and it constitute are introduced. The motion control process based on special-purpose chip is analyzed. The structure of controller software is provided. The methods of typical motion control programming are presented.

Keywords-MCX314; carving machine; motion control

I. INTRODUCTION (HEADING 1)

Numerical control carving machine is applied to advertisement, print, label, mould, woodwork. The Economical numerical control carving system with kernel of DSP motion controller is practical, convenient operation, economical.

Single chip computer is selected as processor of Economical numerical control system, they are 8bit, 16bit or 32bit. System is open loop control and stepper motor is Adopted. Embedded processor and MCX314 DSP are applied to carving system, the system can realize 4-axis motion control, and satisfy multi-coordinate, high accuracy and high speed requirement.

II. HARDWARE STRUCTURE

Basic Mechanical Structure of a CNC Machine includes the three axes that are X, Y, Z which are controlled by MCX series is NOVA electron corp. DSP motion Control special-purpose chip. MCX314 As is a 4-axis motion Control IC which can control 4 axes of either stepper motor or pulse type servo drivers for position, speed, and Interpolation controls. It had been applied to numerical Control machine tool ,carving machine ,industrial robot, etc.,The structure can be built with different structures which may be wood, metal as needed for structure rigidity and for flexibility for movement. The structure varies with area of job can be performed and hardware can be same as three motors for 3 axes controlling , relays for switching, limit switches and IC's like ULN2803 for motor movement.

AT91FR40162 is one of AT91 series microcontroller with ARM7TDMI kernel, High capability Flash, inner SRAM and rich peripheral.

MCX314 has several interpolation methods, different Interpolation methods can be used continuously, linear Interpolation — circular interpolation — linear interpolation. The maximum drive speed of performing continuous Interpolation is 2MHz. MCX314 has constant vector speed Control function; this function performs a constant vector speed. MCX314 has Position Control Function; compare register and software limit function, driving by external signal function, servo motor feedback signals.

Signal function, servo motor feedback signals. AT91FR40162 is CPU and MCX314 is coprocessor. AT91FR40162 sends commands and parameters to MCX314, MCX314 identifies commands, processes signal and outputs driving signal to executing device. At the same Time, AT91FR40162 and MCX314 receive feedback signal and respond correspondingly. As showed in Fig. If the Hardware includes clock, power, debug module, man-machine interface module, driving signal interface module, control signal interface module.

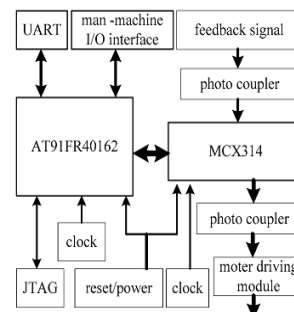


Figure1 .Hardware structure frame of controller

A. Basic Peripheries

MCX314 is supplied by 5V power, AT91FR40162 core Voltage is 1.8V, On-chip peripherals voltage is 3.3V and Other peripherals voltage is 5V .So system

needs three Sources: 5V, 3.3V ,1.8V .5V source is provided by the External, LT1084CT-3.3 and LM317 on board provide 3.3V and 1.8V. The clock of MCX314 is 16MHz, clock signal starts Inner synchronous circuit, clock frequency is standard for driving speed, acceleration/deceleration .A 66MHz oscillator is selected as AT91FR40162'sclock. The JTAG interface of ARM is used to debug the Controller and program the flash in system.

B. Driving Interface

Driving interface circuits are between motion controller and stepper motor. They realize photoelectric isolating and filtering of I/O signal, and amplify the output pulse to drive motor. Optoelectronic isolators are applied to isolate MCX314 from later executing organ and feedback circuits. Optoelectronic isolator can restrain pulse and noise disturbance and improve signal-to-noise ratio. The output signals such pulse, direction and input signals such as limit switches are isolated from controller by TLP521. This can prevent external disturbance from entering main chip.

Signal driving chip ULN2803 is used in output channel, ULN2803 outputting voltage reach to 50V and outputting current reach to 600mA. According to different application, different driving device will be selected.

C. Interface of MCX314 and AT91FR40162

MCX314 can work in 16-bit or 8-bit data bus mode. MCX314 connects AT91FR40162 with 16-bit data bus, data bus width selection pin H16L8 links to high level. With 16-bit data bus 3-bit address bus of MCX314 is used for accessing all the registers. Address bus A0A1A2 connect with A1A2A3 of AT91FR40162, also, write strobe and read strobe of ARM and DSP link. For deal with hardware interrupt of MCX314, the interrupt pin INTO of MCX314 must be set high and linked to interrupt signal IRQO of AT91FR40162.

Fig.2 shows the interface circuit between ARM and DSP.

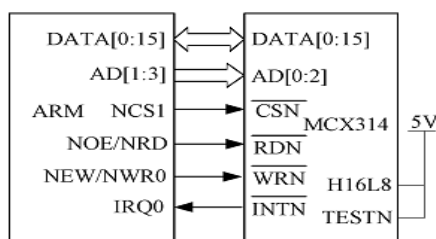


Figure 2. Interface of MCX314 and AT91FR40162

ARM takes MCX314's registers as his off-chip

memory, external bus interface EBI of AT91FR40162 provide signal to access off-chip memory and device, it has eight chip selection signal, among these NCS0-NCS3 are low level effective and CS4-CS7 are high level effective. So NCS1 is selected because MCX314 is low level effective. NCS1 determines MCX314's first address, so the absolute addresses of registers are determined.

III. SOFTWARE DESIGN OF CONTROLLER

According to hardware structure the control system software function is divided into five modules: basic control module, data communication module, man-machine intercourse module, issue disposing module, motion control module. Real-time system uC/OS-II is in charge of managing and scheduling the five missions. Basic control module manages the basic operation of system, including hardware initialization and driving program; data communication module deals with the loading of process code and data receiving-dispatching; man-machine intercourse module deals with keyboard input and the operation messages display, issue disposing module is in charge of exception handling and warning; motion control module includes interpolation computing, the speed and position control of motor. In five missions the motion control is kernel.

A. Process of Motion Control

Bases on DSP MCX314 has plentiful hardware unit and hardware interpolation function, motion control algorithm are realized mainly by its hardware. The motion control system outputs pulse, in the whole process MCX314 output digital signal. Pulse increment interpolation is adopted, the frequency of output pulse controls speed of motor, the quantity of pulse controls the amount of motor running.

MCX314 achieves control function mainly by data communications between registers and CPU. According to the motion rule, the control commands and parameters are written to corresponding registers, simultaneously the values of special registers are read, the feedback signal of MCX314 is detected, so the execution status of MCX314 are obtained, corresponding respond is implemented.

B. Basic Operation Function

Embedded C language achieves system software based ARM. To enhance the universality of the program, according to the hardware structure of MCX314, in header file MCX314.hall registers of MCX314 are defined.

Registers accessing functions are basic operation functions. Functions write commands to MCX314's command registers and read data from status registers to control and detect every axis. The bits of special registers are defined, so bits can be accessed. It requires 250 nS(maximum) to access the command code when CLK=16MHz. The signal BUSYN is on the low level at this moment, the following commands must be written before this time has elapsed.

The basic setting functions based on registers accessing functions. The operation functions implement task such as work mode setting, parameter setting, working status reading, etc. Working mode setting includes interrupt, interpolation mode, driving pulse types, external operation mode, synchronous mode, etc. Parameter settings include arc center setting, speed/acceleration/deceleration setting, range setting, output pulse amount settings. Status readings include logical position counter reading for real position counter reading, current drive speed reading, current acceleration and deceleration reading, synchronous action buffer register reading.

C. Motion Control Function

Interpolation functions are constructed based on basic operation functions. Because of MCX314's hardware interpolation capacity, the interpolation algorithms are realized by inner hardware. The main tasks of interpolation functions are parameter setting, interpolation starting. Basic linear interpolation function, circular interpolation function and bit pattern interpolation function are written according to MCX314's interpolation mode.

Continuous interpolation are necessary in motion control, MCX314 can operate 2-axis and 3-axis continuous interpolations at the same time. The continuous interpolation is executing a series of interpolation processes such as linear interpolation—circular interpolation—linear interpolation.

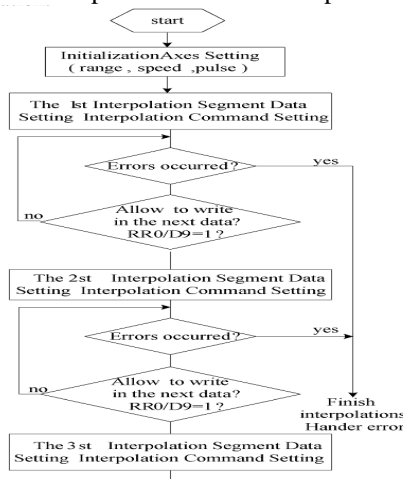


Figure 3. Continuous interpolation process

Fig.3 shows the process of continuous interpolation.

During the continuous interpolation, the driving will not stop; contrarily, the pulses are output continuously. Before setting the interpolation segment, the user should first set other data such as center point finish point... for each segment. When executing the continuous interpolation, the host CPU has to write the next interpolation segment into MCX314As before the previous interpolation segment is finished. So the segment driving time should be longer than the time for error checking and the command setting of next segment during the interpolation.

This is all about CNC Controlling using a DSP and microcontroller here now is the real structure of mechanical terms of the cnc machine included in terms of input given to the structure formed as cnc Machine.

D. Man Machine interface

This Man Machine interface includes the user interface through which we can supply input structure in desired shape through a CNC language which prominently Known as “G-CODE” and “M-CODE”. These G-Code structure are assembled with desired coordinate to work for that set point by the user interface by the user.

In Available CNC market we have so many CNC Controller software's among them MACH3 Controller is More Suggested than any other like linux CNC.

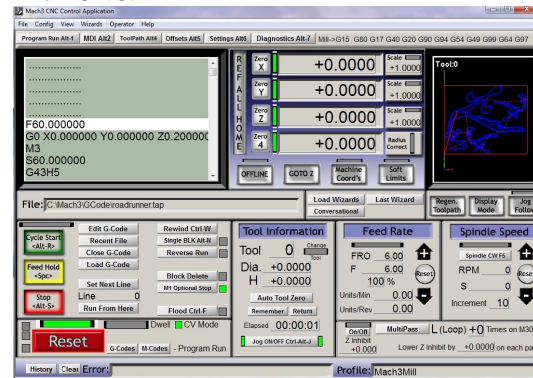


Fig.3 shows the Mach 3 CNC Main Screen Layout.

IV. CONCLUSIONS

Numeric control carving machine with 3-axis simultaneous-motioned locates in domestic universal demands. Controller is realized based on embedded microprocessor and motion control technique. Controller is easy to extend, so it is universal and its capability price ratio is high. In experiment the controller shows its feature of quick response, high reliability. It's a high performance and low cost option for corporation.

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RISK ASSESSMENT IN DIESEL ENGINE USING FMEA ASSISTED DEMPSTER -SHAFFER EVIDENCE THEORY

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Abstract The diesel engine is recognized as the most promising powertrain in the foreseeable future due to its superior thermal efficiency and reliability. Their reliability seriously affects the overall Diesel engine and its performance. Failure mode and effects analysis (FMEA), especially, the risk priority order of failure modes, is essential in the design as well as process. The risk priority number (RPN) has been extensively used to determine the risk priority order of failure modes. When experts give different risk evaluations to one failure mode, which may be imprecise and uncertain, the traditional RPN is not a sufficient tool for decision making of risk evaluation. In this paper, the modified Dempster–Shafer (D–S) is adopted to aggregate the different evaluation information by considering multiple experts’ evaluation opinions, failure modes and three risk factors respectively. A simplified discernment frame is proposed according to the practical application. Moreover, the mean value of the new RPN is used to determine the risk priority order of multiple failure modes. Finally, this method is used to deal with the risk priority evaluation of the failure modes in head gasket of Diesel engine under multiple sources of different and uncertain evaluation information.

INTRODUCTION:

The diesel engine has been widely used in commercial vehicles, industrial applications and today’s passenger cars and light-duty trucks. Modern emissions standards and customer demands are driving diesel engineering to become a fast growing applied engineering discipline in order to meet the requirements of designing optimum diesel engines. The engineering population in diesel engine design is growing fast. The need for advanced design theories and analysis techniques for improve reliability in diesel engine performance analysis and system design. Diesel engine design is very complex. It involves many people and companies from OEM (original equipment manufacturer) to suppliers. A system design approach to set up correct engine performance specifications is essential in order to streamline the process.. A cylinder gasket present between the engine block and cylinder head in the internal combustion engine, its application is more critical component and play a vital role in Diesel engine. . The major function of cylinder gasket role is ensure the maximum pressure compression and prevent leakage of coolant or engine oil into the cylinders. In this paper the application of proposed method on Diesel engine head gasket.

FAILURE MODE EFFECT ANALYSIS:

The Failure Modes and Effect Analysis is a systematic method of identify the various potential mode, their causes, effects on system performance and mitigate product and process problems before they occur. FMEA is a powerful reliability analysis tool that provides a mean to compare, from a risk point of view, alternative machine system

configurations. FMEA is applicable at various levels of system decomposition from the highest level of block diagram down to the functions of discrete components. FMEA should be updated throughout the entire system’s life. Whereas anticipating each failure mode is not possible, the improvement squad ought to invent as extensive a record of likely failure modes as probable. FMEAs also carry chronological information for use in upcoming product development. Various types of FMEA are System FMEA, Design FMEA, Process FMEA, Service delivery FMEA and more. FMEA is an analysis technique for defining, identifying and eliminating known and/or potential failures, problems, errors from systems, design, processes, and/or services before they reach the customers. FMEA can facilitate the identification of potential failures in the design or process of products or systems. This can help designers adjust the existing programs, increase compensating provisions, employ the recommended actions to reduce the likelihood of failures, decrease the probability of failure rates and avoid hazardous accidents. FMEA has been extensively used in a number of industrial products, including structures operating in power, aeronautics and astronautics. FMEA can identify each possible failure mode and determine the effect of each failure. However, there can be multiple failure modes and their risks and effects are different.

METHODOLOGY:

he risk associated with uncertainty or variability can be classified into system risk and design risk for an engine product. The risks are managed through FMEA (failure mode effect analysis). A system/design FMEA approach usually consists of

the following three steps:

1. Assess risk by identifying potential failure modes, the likelihood of occurrence, and the severity of their effects.
2. Establish priorities by ranking the failure modes with the risk priority number (RPN).
3. Take action to implement recommendation to minimize the risk.

Table 1 :Rating for occurrence of a failure in FMEA as suggested.

	Probability of occurrence	Possible failure rate
10	Extremely high: failure almost	P1/2
9	Very high	1/2
8	Repeated failures	1/7
7	High	1/15
6	Moderately high	1/50
5	Moderate	1/300
4	Relatively low	1/1500
3	Low	1/15000
2	Remote	1/150000
1	Nearly impossible	61/1500000

Table 2 : Rating for severity of a failure in FMEA as suggested criteria.

Rating	Effect	Severity of effect
10	Hazard	Highest severity ranking of a failure mode, occurring
9	Hazard	Higher severity ranking of a failure mode, occurring
8	Extrem	Operation of system or product is broken down
7	Major	Operation of system or product may be continued
6	Signific	Operation of system or product is continued and
5	Moderate	Performance of system or product is affected
4	Low	Performance of system or product is small affected
3	Minor	System performance and satisfaction with minor
2	Very	System performance and satisfaction with slight
1	None	No effect

Table 3: Suggested criteria of rating for detection of a failure in FMEA.

Rating	Detection	Criteria
10	Absolute Uncertainty	Potential occurring of failure mode cannot be detected in concept, design and process FMEA/mechanism and subsequent failure mode
9	Very remote	The possibility of detecting the potential occurring of failure mode is very remote/mechanism and subsequent failure mode
8	Remote	The possibility of detecting the potential occurring of failure mode is remote/mechanism and subsequent failure mode
7	Very low	The possibility of detecting the potential occurring of failure mode is very low/mechanism and subsequent failure mode
6	Low	The possibility of detecting the potential occurring of failure mode is low/mechanism and subsequent failure mode.
5	Moderate	The possibility of detecting the potential occurring of failure mode is moderate/mechanism and subsequent failure mode
4	Moderately high	The possibility of detecting the potential occurring of failure mode is moderately high/mechanism and subsequent failure mode
3	High	The possibility of detecting the potential occurring of failure mode is high/mechanism and subsequent failure mode
2	Very high	The possibility of detecting the potential occurring of failure mode is very high/mechanism and subsequent failure mode
1	Almost Certain	The potential occurring of failure mode will be detect/mechanism and subsequent failure mode

Consequently, the ability to prioritize risks is important; the risk priority number (RPN) offers one way to rank failure modes. In general, RPN includes three factors: the severity of a failure effect (S), which

is a numerical subjective estimation of the degree of severity of the consequence of a occurred failure, the probability of the occurrence of a failure mode (O), which is a numerical subjective estimation of the likelihood of the cause, and the probability of a failure being detected (D), which is a numerical subjective estimation of the effectiveness of the controls preventing or detecting the cause or failure mode. Each factor uses a numeric scale (rating) from 1 to 10, as expressed in Tables 1–3. These ratings are

then multiplied to obtain RPN, expressed as For calculating the risk in FMEA method, risk has three components which are multiplied to produce a risk priority number (RPN):

1. Severity (S): Severity is described on a 10-point scale where 10 are highest.
2. Occurrence (O): Occurrence is described on a 10-point scale where 10 are highest.
3. Detection (D): Detection is described on a 10-point scale where 10 are highest.

$$RPN = S \times O \times D$$

Where RPN min = 1 while RPN max = 1000.

In this paper PFMEA model for Diesel engine process analysis using FMEA based RPN method. It estimate the various Failure modes its effects and prioritize its root cause to reduce failure and consequence effect by improving reliability in cooling system and mitigate the failure modes. The method included assessing risk factors using belief structures, synthesizing individual belief structures into group belief structures, aggregating the group belief structures into overall belief structures, converting the overall belief structures into expected risk scores and ranking the expected risk scores using the mini max regret approach (MRA). Inspired by this work, this paper uses the modified D-S evidence theory to aggregate the different opinions which may be imprecise and uncertain. The method is used to deal with the risk priority evaluation of process failure modes in diesel engine. The rest of this paper is organized as follows. In Section 2, the D-S evidence theory is briefly introduced. In Section 3, new RPN model using modified D-S evidence theory is proposed. Section 4 uses the novel model for risk priority evaluation of failure modes in diesel engine. The final section makes the conclusions.

D-S EVIDENCE THEORY:

The evidence theory is developed and presented by Shafer [15] based on Dempster’s work [16] on milestones on the upper and lower bounds of belief assignment to the hypothesis, also called Dempster–Shafer (D–S) evidence theory. The D–S evidence theory adopts the belief interval to describe the uncertainty of the hypothesis. Moreover, the method can deal with the information of multiple sources which may be imprecise, uncertain and incomplete. The D–S evidence theory can aggregate multiple sources of evidence through the combination rule. Dempster’s combination rule is expressed as follows. Given two basic probability assignment functions $m_i(X)$ and $m_j(Y)$, the Dempster’s combination rule can be defined by

$$m(C) = (M_i \oplus M_j)(C) = \begin{cases} \frac{\sum_{X \cap Y \neq \emptyset} m_i(X) * m_j(Y)}{1 - \sum_{X \cap Y = \emptyset} m_i(X) * m_j(Y)} \\ 0 \end{cases}$$

Where $\Theta = \{1, 2, 3\}; i=O,S,D; n=1,2,...N; n \in \mathbb{N}, M(X), M(Y) \rightarrow$ multiple possible events and $m(C)$ denotes the BBA of c that is supported by i th (j th) evidence.

RISK PRIORITY NUMBER MODEL USING D-S EVIDENCE THEORY:

As briefly introduced above, D–S evidence theory employs the confidence interval to describe the uncertainty of hypothesis and can deal with the incomplete, imprecise and uncertain information of system. Moreover, the new aggregated belief assignment can be attained through a combination of

multiple sources of evidence using combination rule. Furthermore, owing to the flexibility of the basic axioms in evidence theory, no further assumptions are needed to quantitate the uncertain information of the system [18]. In this section, the modified D–S evidence theory is used to deal with and model the difference and uncertainty of evaluation information received from multiple experts in FMEA. The method aggregates evaluation information of multiple experts about risk factors. The evaluation consequence of each expert with respect to each risk factor of each failure mode is regarded as a new evidence body.

PROPOSED RISK PRIORITY NUMBER:

This new BBA can be regarded as a degree of belief in these ratings. Because BBA satisfies the axiom of additivity, the belief degrees can be the probability of rating of the risk factors. The three risk factors can be considered as discrete random variables. The RPN is a function of the discrete random variables. Consequently, the RPN is a discrete random variable with several different ratings and the corresponding probabilities. Suppose RPN has several ratings (r_1, r_2, \dots, r_n) ,

with respective probabilities $P(r_1), P(r_2), \dots, P(r_n)$

for n th failure mode through using random theory. In order to compare the overall risk of each failure mode, the mean value of RPN is needed, which can be defined as following:

$$MVRPN_n = E(RPN_n) = \sum_{q=1}^n (RPN_n^q) * P(RPN_n^q).$$

APPLICATION ANALYSIS OF THE PROPOSED APPROACH IN DIESEL ENGINE HEAD GASKET:

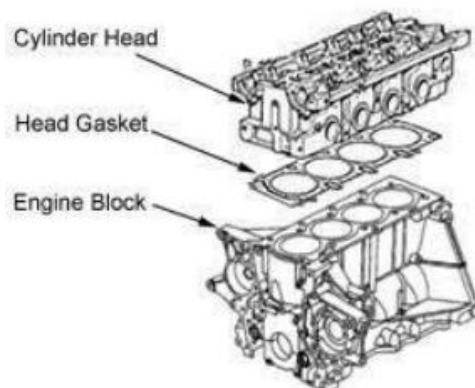


Fig: Diesel Engine cylinder Gasket

ITEM	FAILURE MODE	CAUSE	EFFECT	ALARM
1	Gas leakage	Decrease the inlet fuel pressure at moth of cylinder.	Power reduction, fire , explosion	yes
2	Crack	Thermal Fatigue	Poor performance of gasket. Loss of pressure	no
3	Coolant Leakage	Glue ring aging, Permanent Deformation	Over heat, erosion	Yes
4	Corrosion	Impure fuel mix with moisture	overheat	No
5	Improper gasket bore diameter	Unreasonable design of dimension chain	Bursting pressure increase; power reduction	yes

Risk Factor Find by expert 1:

Item	Risk factor rating		
	Severity(s)	Occurrence (O)	Detection (D)
1	8:60%	3	4
	9:40%		
2	8	3	4
3	7	4:80%	2
		5:20%	
4	10	1	6
5	7	4	3:90%
			4:10%

The mean value of RPN of five failure mode are find using following formula

$$MVRPN = \sum (RPN_n) = \sum (S \times O \times D) \times P$$

For example the MRPN value for first item calculation is shown below.
 $MVRPN_1 = \sum (RPN_1) = 3 \times 0.40 \times 3 \times 4 + 9 \times .60 \times 3 \times 4 = 79.2$

Similarly all other failure mode, the mean value of risk priority number is calculated and articulated.

Failure Mode	ITEM No				
	1	2	3	4	5
MPRN	79.2	96	67.2	60	109.2

From the above table RPN vale is high in 5th failure mode in diesel engine head gasket. The risk priority of failure modes are 5,2,1,3 and 4 in order from this we can find the lowest priority of failure mode is component 4 which has least risk. The value of risk is compared with the historical data with practical engineering background and shows the modified FMEA techniques is more efficient than previous

methods.

CONCLUSIONS:

Dempster–Shafer evidence theory is more useful and systematic tool to find the risk evaluate in diesel Engine component in effective way and which may be inconsistent, imprecise and uncertain. In this paper the DS evidence theory is proposed for dealing with multiple failure modes and three risk factors in RPN analysis of FMEA Diesel Engine head gasket. Consequently, the RPN is a function of the discrete random variable. The RPN is used for the risk priority ranking of failure modes. The proposed method is demonstrated by an application of risk priority ranking of failure modes in FMEA in Diesel Engine head gasket. The evaluation information of various failure modes is aggregated and RPN is obtained and priority of risk component is evaluated.

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LEAN TRANSFORMATION FOR GREEN AND FINANCIALLY VIABLE FOUNDRIES

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Abstract: Lean manufacturing is a business model and collection of tactical methods that emphasize eliminating non-value added activities while delivering quality products on time at least cost with greater efficiency. However only recently have studies linked lean management philosophies with improving environmental sustainability. These studies suggest that lean manufacturing is more than a set of lean tools that can optimize manufacturing efficiencies; it is a process and mindset that needs to be integrated into daily manufacturing systems to achieve sustainability. The foundry industry, as well as manufacturing in general, has significant challenges in the current regulatory and political climate with developing an economically and a green business model. Lean manufacturing has proven itself as a model for both economic and environmental sustainability. Several recent studies have shown that both lean and green techniques and “zero-waste” policies also lead to reductions in overall cost. These strategies have been examined for the foundry industry. This paper will review the current literature and describe how lean and green can provide a relevant framework for environmentally and economically sustainable foundries. Examples of lean and green technologies and techniques which can be applied to foundries in an Indian context will be described.

Key words: Green manufacturing; lean manufacturing; environmental sustainability; pollution control.

1 INTRODUCTION

The foundry industry faces specific challenges with respect to economic and environmental sustainability. Foundry processes require substantial energy, typically generated using fossil fuels; whether onsite or remotely at an electrical power plant. Melting the material consumes the majority of this energy; however, other energy intensive processes such as heat treatment are also included in many foundry operations. Also, a majority of foundries utilize sand as a molding material. The binders utilized can often include organic compounds, and, when pollutants which are regulated burned out in the casting process, release volatile organic compounds and hazardous air. The casting finishing process can also utilize organic materials which can result in environmental impacts [1]. Figure 1 shows a diagram of a typical foundry with potential waste streams.

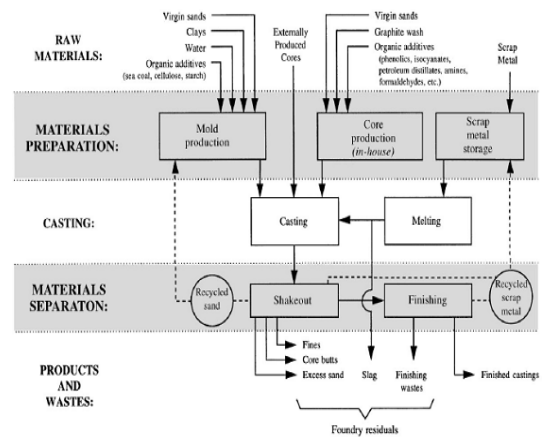


Fig. 1: Diagram of a typical foundry with potential waste streams.

Being foundry industry having environmentally sensitive processes, the business structure of it has hindered its ability to develop and implement sustainable practices. The industry is primarily made up of small foundries with unique product and process combinations limiting the ability to develop technologies that benefit a large group of foundries. The small size of the businesses means that new energy saving technologies cannot be effectively capitalized. Also,

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because castings are typically viewed as a commodity by purchasers, profit margins are slim leaving little for the capital investment for major process changes. In addition, because many foundry processes such as melting furnaces and casting shakeout have exhaust systems subject to regulation, changes to these systems require lengthy environmental permitting procedures [1].

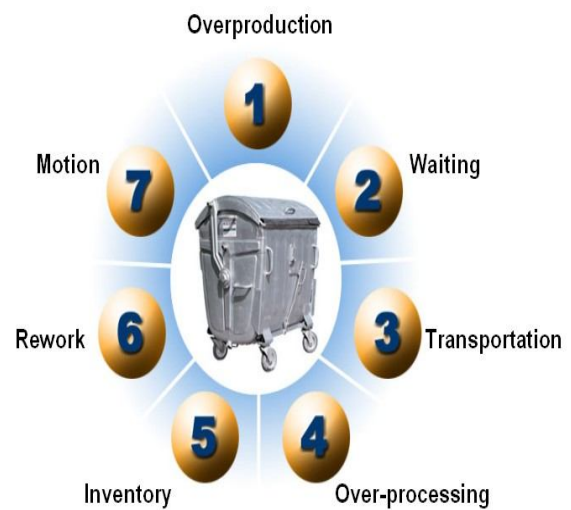
Despite the challenges, castings will continue to be critical components for many of the essential products for both developed and developing countries. Foundries can become economically and environmentally sustainable businesses with the systems approach offered by implementing lean and green methodologies.

2 LEAN METHODOLOGIES

The lean manufacturing movement was first brought light in contemporary manufacturing by a five-year study done at Harvard University by Womack, Jones, and Rose which was published in a book called “The Machine that Changed the world” in 1990 [3]. In this book, the history of the automobile industry was studied and the quality and productivity improvement techniques applied by Toyota were termed “lean production”. This production system, termed the Toyota Production System, TPS, is the over-arching framework and philosophy that can be used to organize manufacturing facilities and processes as well as to restructure suppliers and customers to provide best quality, lowest cost, and shortest leadtime through the elimination of the several forms of waste and involving all the employees [4].

Despite Toyota’s recent success applying a lean philosophy, Henry Ford is considered by some to be the father of lean thinking, and was reportedly a master at finding waste. In 1930 in his book “Moving Forward” Ford said, “It is the

little things that are hard to see – the awkward little methods of doing things that have grown up and which no one notices. And since manufacturing is solely a matter of detail, these little things develop, when added together, into very big things” [5]. Waste reduction is typically seen as the heart of the “Lean Philosophy.” Waste is broadly defined and can be thought of in a variety of ways. In his book on “Ford’s Lean Vision”, Levinson uses the word friction instead of waste. Friction can be defined as chronic problems and inefficiencies that become accepted aspects of a job and limit productivity [5]. The lean literature typically identifies seven or seven specific types of waste that must be attacked on the journey to lean. (Table 1)



7 common types of waste present in a production system

Table 1: Seven types of wastes targeted by lean philosophy [6-7]

Sl.no	TYPE OF WASTE	Examples (CoreShop)	Environmental Impacts
1.	Over Production	Mis-Match of Cores/Un-Balanced Core Production	(a) More raw materials and energy consumed in making the unnecessary products. (b) Extra products may spoil or become obsolete requiring disposal. (c) Extra hazardous materials used result in extra emissions, waste disposal, worker exposure, etc.
2.	Scrap and Rework	(a) 22% Rejection at the shop leads to Scrap, like soft blow, cracks, over cured blocks(oven), handling breakage etc., (b) Dressing	(a) Disposal requirement of sand with resin and hardener. (b) unnecessary processing increases wastes, energy use and emissions.

3.	Waiting	(a) Robo line cycle time limited to 60sec & due to waiting for Painting/gluing etc., (b) Robo line final output path dependent on Manual Operation – Unbalanced. (c) Waiting time at oven.	(a)Waiting time of oven routing in extra consumption of LPG and corresponding CO ₂ generation. (b)Wasted energy from heating, cooling, and lighting during production downtime.
4.	Inventory	(a) Finished Goods inventory in finishing area. (b) Work In Progress (WIP) inventory at each Painting/ assembly station.	(a)Extra space required for the storage this leads to energy consumption for lighting. (b)More packing to store WIP (c)More materials needed to replace WIP.
5.	Transport	Movement of Unpainted and Painted Cores due to scattered Location of Sub-Assemblies and Assembly Stations.	(a)More energy used for transport. (b)More space required for WIP movement, increasing lighting, heating, and cooling demand and energy consumption. (c)Damages and spills during transport.
6.	Motion	(a) Lack of Storage space/Racks/Trolleys next to Production/Assembly area. (b) Operators Move to pick and Place the Cores leads to fatigue etc.,	More packing required to protect components during movement.
7.	Over Processing and Adjustments	Excess Amine Consumption in Cold Box due to Faster Processing (Process steps that are not required)	(a)Excess amine consumption leads to increased leakage. (b)Transportation of Hazardous materials requires special shipping and packaging. (c)Unnecessary processing increases wastes, energy use and emissions.

As greater companies attempted to become lean and struggled with lean implementation, it became apparent that applying lean as only set of tools on the production floor did not work. In his follow up book about lean manufacturing, Womack tackled the process to become lean and defined five-Steps to guide its successful implementation [8]. These are:

- (1) Specify value from the standpoint of the end customer by product family.
- (2) Identify all the steps in the value stream for each product family, eliminating whenever possible those steps that do not create value.
- (3) Make the value-creating steps occur in tight sequence so the product will flow smoothly toward the customer.
- (4) As flow is introduced, let customers pull value from the next upstream activity.
- (5) As value is specified, value streams are identified, wasted steps are removed, and flow and pull are introduced, begin the process again and

continue it until a state of perfection is reached in which perfect value is created with no waste [8].

In 1988, the Shingo Prize, named for the industrial engineer Shigeo Shingo, was established. This prestigious prize was developed to honor the lifetime of work Shingo spent studying and developing lean cultures. The Shingo Prize Model (Fig. 2) however, is not just a production floor model. It is an overall systems model that incorporates all aspects of business operations and processes. The model was developed to promote lean/world-class business practices that result in inability to compete globally and demonstrates that culture is the foundation of a lean enterprise [9]. The Shingo Prize uses business metrics as a measure of success; thus, only companies whose positive results are driven by the transformation to lean are given recognition.

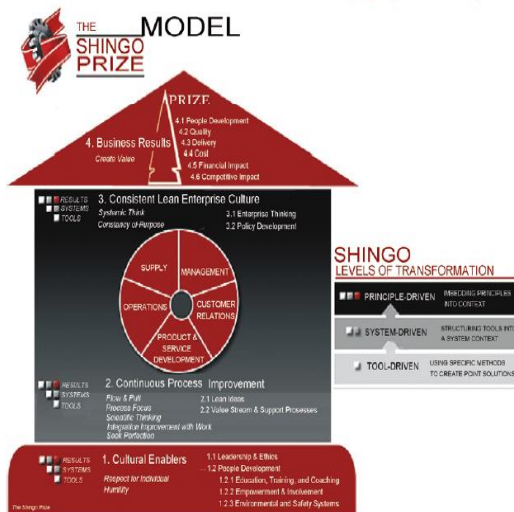


Fig. 2: Shingo Prize Model for lean enterprise

The Shingo Model recognizes “Cultural Enablers” as the foundation of a lean enterprise. Culture as a central lean implementation requirement is reiterated in the US Environmental Protection Agency (EPA) study of lean manufacturing and agreed upon by many other studies [6,10-13]. The EPA study exemplifies the characteristics of a successful lean organization with the following four statements:

- A continual improvement culture focused on identifying and eliminating waste throughout the production process;
- Employee involvement in continual improvement and problem-solving; Operations-based focus of activity and involvement;
- A metrics-driven operational setting that emphasizes rapid performance feedback and leading indicators; Supply chain investment to improve enterprise-wide performance; and
- A whole systems view and thinking for optimizing performance [6].

Lean is not a set of tools, it is a corporate philosophy and culture that abhors waste and works to optimize the enterprise as a system using several tools and techniques. From a sustainability perspective many, if not all, environmental impacts can be viewed as waste and must therefore be driven by poor systems thinking. It seems natural that the lean philosophy can be used as a powerful tool to improve Environmental sustainability. The foundry industry in particular is an industry where efficient production and environmental impacts are closely tied, so the implementation of lean and green philosophies can have a powerful effect on a foundry's economic and environmental sustainability.

3 Environmental sustainability

Sustainability was explained by the International Union for Conservation of Nature in a 1969 mandate as “achieving economic growth and

industrialization without environmental damage” [14]. In part due to some highly visible ecological disasters, the concept gained more traction in 1983 when the United Nations published a report from the World Commission of Environment and Development, (now called the Brundtland Report), where sustainability was redefined as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” [15-17]. Environmental sustainability can be thought of in terms of natural capital, as the source for inputs and the sink for wastes such that you have both sustainable production and sustainable consumption within the Biophysical limits of the overall ecosystem. However, the ability to balance production and consumption and also improve society with economic development is hard to measure resulting in little agreement on natural capital approaches to drive sustainability [18]. While definitions of sustainability are somewhat vague and a clear sustainability index is not agreed upon, most agree that there are three components to a comprehensive sustainability picture: economic, social and environmental [14]. This paper is focused on economic and environmental sustainability and will not discuss the social sustainability component.

Since the early 1990s environmental legislation and international environmental agreements have expanded greatly, driving global environmental policy changes [14]. It is in response to these policy changes, regulations, and the resultant increased public awareness that many companies have developed strategies and practices to become more environmentally sustainable. One such strategy is adopting Environmental Management Systems (EMS).

In line with the management systems standards, evaluation and auditing tools, and product-oriented support tools [23]. Under ISO 14000, the specifics of a company's EMS are defined in the first category, management system standards. In 2001, the US EPA published a general implementation guide for EMS, which follows the ISO 14000 standard closely [24]. ISO 14000 mirrors the ISO 9000 quality management system standards. Both focus on systemic prevention rather than inspection (in the case of quality) and cleanup (in the case of the environment); and also prescribe a system for continuous improvement [15]. ISO 14000 does not require specification of clear environmental targets or guidelines; however, many companies who have implemented ISO 9000 quality improvement strategies and targets have also implemented similar ISO 14000 environmental strategies and targets [25]. An illustration of how various elements of an ISO 14000 EMS fit together is provided in Fig. 4 [26].

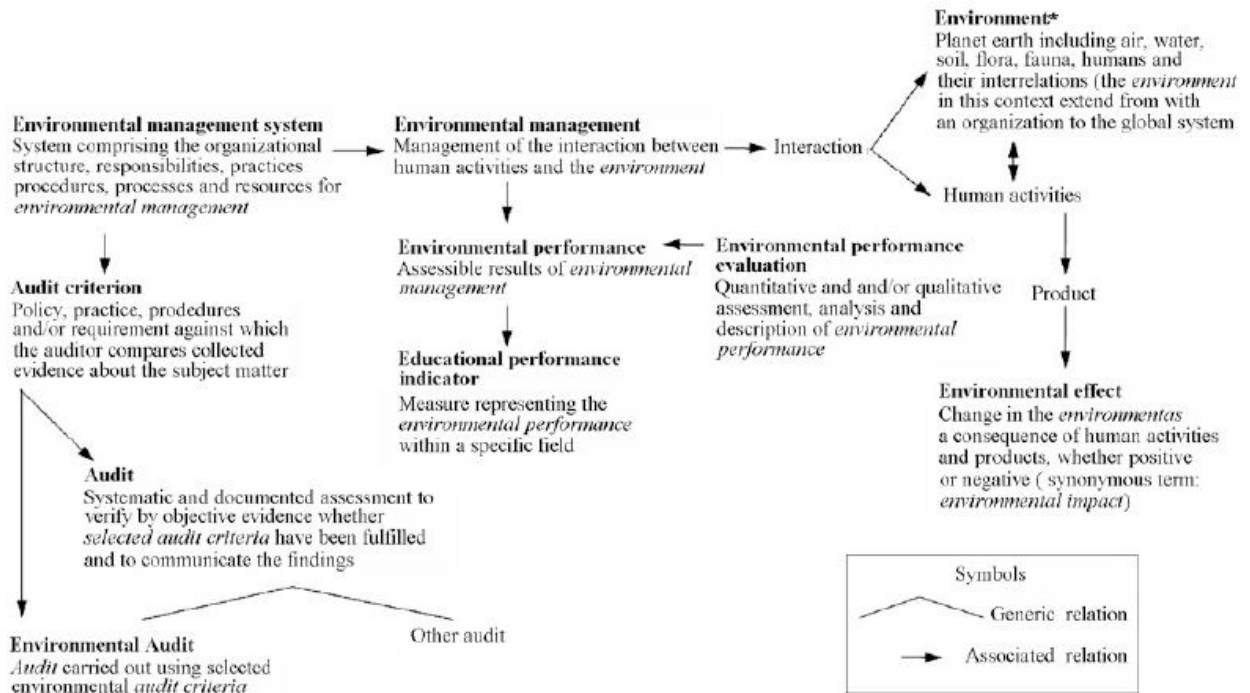


Fig. 3 Concept Diagrams and Definitions related to Environmental Management



Fig 4: ISO 14000 Elements and how they interact

United Nations Conference on Environment and Development in Rio de Janeiro in 1992, the ISO 14000 Environment Management System standard was developed and published in 1996 [19-20]. The ISO 14000 standard is a widely used EMS, and will be used in this paper to illustrate EMS concepts and Practices for environmental sustainability. The motivations used by companies for adopting EMS

standards are mixed and they include industrial customer requirements, internal improvements, company image and better relationships with regulators [20-21].

The general nature of the ISO 14000 system illustrated in Fig. 3 demonstrates the basic concepts and definitions of environmental management [22].

ISO 14000 standards and guidelines can be grouped into three broad categories;

Some type of Environmental Management System is an essential tool that must be used to ensure environmental sustainability for companies around the globe. The debate on the appropriate measures and subsequent regulations for environmental sustainability continues, and in response, more companies continue to be impacted by the increasing number of environmental regulations and policies. The foundry industry is increasingly impacted by new regulations and guidelines, and thus tools and techniques for managing environmental sustainability are very important.

4 Studies linking lean methodologies with environmental sustainability

Before 2000, strong links between the implementation of lean philosophies and improved environmental sustainability could be found in words only. An early reference found in the Harvard Business Review (HBR) article casts doubts on whether win-win situations can be found for business when trying to improve environmental sustainability. However, the article concludes that environmental impact management needs to be managed as trade-offs using a value based approach, philosophically very similar to the lean approach [27]. Also in 1994, The United States President's Commission on Environmental Quality issued a report on "Total Quality Management: A Framework for Pollution Prevention" where TQM and pollution prevention were seen as complementary processes [28]. While this report received limited exposure, the direct application of lean philosophies, such as TQM, to environmental sustainability had not been previously reviewed. The report also lists success stories where TQM had tremendous impact on pollution prevention [28]. Later, results of a 1996 study found that adopting manufacturing process innovation (this study's term for lean) incentivized the adoption of environmentally friendly manufacturing practices. The adoption of lean techniques drove the adoption of green design and manufacturing because they are structured by similar principals: a dedication to productivity, quality, and cost reduction, continuous improvement, and technological innovation [29]. A second Harvard Business Review article states that enhanced resource productivity, those things that also drive reduced environment impact, can be expected to enhance corporate competitiveness. Secondly, this article suggests that properly designed regulations would trigger innovation that would improve cost, improve value, and at the same time improve environmental impacts [30]. A 2000 study on the furniture industry using interviews and surveys found

that despite seeing the environment and lean practices, such as Just In Time (JIT) or Total Quality Management, as separate initiatives, process changes for the improvement of environmental performance delivered competitive economic performance improvements [31].

Corporate action linking lean techniques and green sustainability have been accelerated since 2000; there is a growing body of literature linking the two. Environmental sustainability management activities have been studied focusing on different areas of lean: manufacturing; supply chains; management, organization structure and community partnerships; and enterprise. Recognizing that lean manufacturing methodologies were a leading manufacturing paradigm, and that lean efforts in the area of waste reduction had great potential to create positive environmental outcomes. The US Environmental Protection Agency (US EPA) commissioned 5 test cases at the Boeing Company to focus on lean waste reduction [32]. This US EPA study came to the following conclusions:

- Lean produces significant resource productivity improvements which lead to environmental improvements.
- Lean produces a robust waste elimination culture.
- Lean thinking brings powerful financial incentives to resource conservation and pollution prevention improvement [32].

Subsequently, in 2003 the US EPA issued another report on lean manufacturing and the environment, and dedicated a portion of their website (www.epa.gov/lean) to the link between lean manufacturing and environmental sustainability [6]. The USEPA has also published toolkits for applying a few chosen lean tools to improve environmental impacts and energy efficiency [7,33]. The lean and environment toolkits identify the environmental impacts that could result from six of the eight types of waste targeted by a Lean Philosophy. These environmental impacts are listed in Table 1 alongside the 8 wastes targeted by lean manufacturing.

An data mining of over 17,000 firms using large scaledatabases from several sources using a regression model found that adopters of ISO 9000 were more likely to also adopt ISO 14000. Also, adopters of ISO 14000 had lower total emissions, and, lean producers and lower inventories were complementary to waste reduction and pollution reduction [34]. The book "Henry Ford's Lean Vision: Enduring Principles from the First Ford Motor Plant" asserts that with aggressive use of lean techniques, adding an ISO 14000 EMS is not only free, but profitable. He further states that lean, ISO 9000 and ISO 14000 are not separate activities, but mutually supportive. The ideal implementation of lean is to have nothing to salvage, meaning that materials have been used productively or not at all, which in

turn leads to better resource productivity. Numerous examples are given where waste products become by-products which are either used or sold [5]. More recently, lean operating systems and environmental management systems were compared and parallels similar to those identified by the earlier US EPA Boeing study were found. Those parallels were expanded and led to the development of the comprehensive lean and green system model shown in Fig. 5. These comparisons concluded that the strength of the management system correlates with the

positive business results for both lean and green [35].

A statistical analysis of green management system measures against the Shingo Prize scoring elements Shingo Prize winners from 2000 to 2005 showed that green manufacturing initiatives improved lean implementation scores. This finding reinforced findings that lean by itself does not drive environmental improvements, but is synergistic when



Fig. 5: Comprehensive lean and green system model

Environmental initiatives are included. The use of less toxic, more recyclable, or more easily processed materials was significantly correlated to increased profits as well as increased customer satisfaction and profitability [36].

Analysis on lean supply chains show mixed results when looking at resulting improvements in environmental sustainability. Green Value Stream Mapping is a holistic approach to remove waste from the entire supply chain resulting in increased customer value and efficient resource utilization, thus decreasing environmental impact [37]. However, enforcing green concepts into the supply base can be tricky [38]. Suppliers may balk if environmental activities reduce their profits, as a reduction in overall material usage is wont to do; thus strong supplier relationships are a key element in effective lean and green initiatives. A simulation model of a generic supply chain including various lean techniques tested the assumption that lean systems compress time-to-market, and in turn reduce a key environmental performance factor - carbon dioxide (CO₂) emission. The resulting analysis showed that the CO₂ emissions were very sensitive to raw material delivery frequency and mode, and that implementing lean techniques, especially in the supply chain portion of the enterprise, did not drive environmental improvements if the environmental impacts were not a direct measure along with other business measures [39]. Supply chain and supplier relationships were again noted as an important part of any lean

enterprise. The link between two specific lean practices, continuous improvement and supply chain practices, and environmental management programs were evaluated. Effective environmental management was found to have a significant positive impact on delivery, confirming the synergistic relationship between environmental activities and lean implementation. The alignment between environmental activities and lean activities has been found to be a critical factor in company competitiveness [40].

In adjoining to the relationships with the supply base, many papers have highlighted the impact of organizational structure and community partnerships (such as those with regulators) are important to the success of environmental sustainability within a lean framework. The implementation of lean and the role of employees at all levels in environmental improvements are discussed using data from the Toyota / GM joint venture, New United Motor Manufacturing (NUMMI). The role of specialist staff, especially the environmental engineer, is critically important in making environmental improvements; however, more than one type of knowledge is required. Thus culture and management structure, especially those fostered by lean enterprise thinking, encourages the combination of knowledge sets to make environmental improvements [11]. It has also been reported that environmentally sensitive processes were more difficult to make lean and will require technical innovation and closer ties with regulatory agencies [6] [32].

It should be noted that investment in environmental abatement technologies is counter to lean philosophies in that abatement does not directly improve the value of the product to the customer and can be considered non-value added in all cases [41].

Finally, lean thinking dictates that the economic and environmental sustainability of a company should consider the both a holistic enterprise view of the company and the product life cycle. The integration of environmental and economic sustainability can be viewed from an operational and a strategic perspective. In the late 1990's Ford Motor Company adopted environmental sustainability as a corporate strategy. This strategy was instrumental in Ford launching the first American built hybrid, the Escape, and in the construction of the Ford Rouge Center which includes a green roof and ten acre sedum garden. Figure 6 shows one framework

for manufacturing sustainability which includes three dimensions of sustainability, three strategies for sustainability, and four layers of corporate organization. This viewpoint is reflected in the research findings that traditional economic variables are now being combined with ecological metrics. The authors also performed a simulation of Lean methods such as Zero Defects and Kanban in different combinations and compared the impacts on the ecological metrics such as energy usage. Production efficiency is positively correlated with production efficiency. They also concluded that lean production techniques alone won't yield ecological benefits. A holistic enterprise view of lean and sustainability is required to make the correct trade-offs [4].

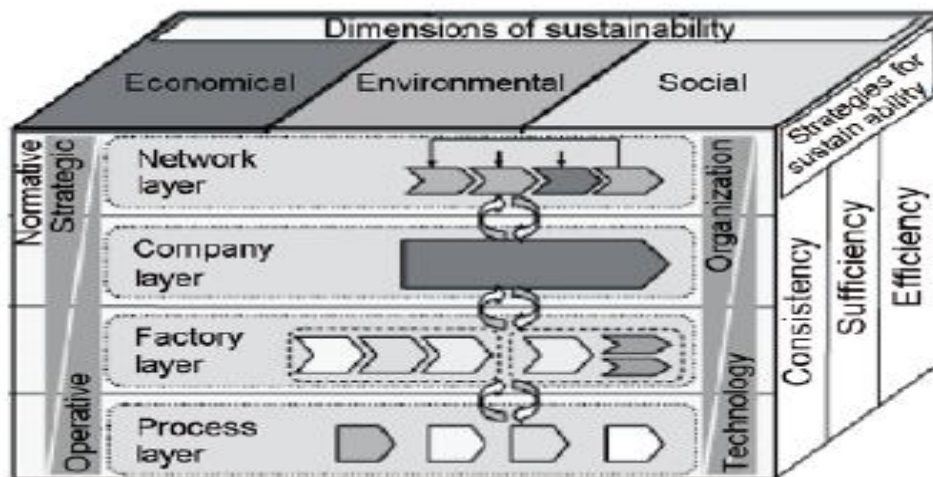


Fig. 6: Framework for Sustainable Manufacturing

Although the integrated enterprise view and the product lifecycle view can help generate sustainability ideas for potential synergies outside of the normal scope of a given manufacturing site; they add a complexity to the implementation of ideas to improve lean and green efforts which are beyond the capacity of many small and medium-sized organizations.

Foundries are contended by highly regulated, energy-intensive processes; however, the successful integration of lean and green in the foundry industry has been demonstrated. In the late 1990s Ford's Windsor Aluminum plant became the first North American metal casting plant to be awarded ISO 14001 registration, and included the EMS as part of their overall lean operating philosophy. Literature and experience demonstrate that the synergy between the efforts offer great benefits to the foundry industry.

5 Framework for foundry lean and green implementation

In Fig. 7 a framework for implementing lean and green methodologies is illustrated. The bedrock for implementation is the organizational philosophy. The supporting pillars for implementation is process improvement: throughput improvement, energy efficiency, innovative technology, and community partnerships.

Organizational Philosophy - Lean manufacturing, including environmental sustainability, is an organizational philosophy or mindset, not a set of tools which can be used selectively. Lean thinking is synonymous with systems another view of sustainable manufacturing is the three legs of the triple bottom line concept - people, planet, and profit (i.e., social equity, environmental quality, and economic

prosperity) as synergistic measures of the success of a given enterprise. This viewpoint drives a recommendation for using an integrated material, energy, and waste flow model which includes the generic life cycle of the manufacturing system.

The scope of the model would include product design, process selection, and facility design because all three have an impact on life cycle.



Fig. 7: Framework for foundry and green implementation.

Thinking; optimizing the whole against multiple objectives. To maximize waste reduction of all forms the philosophy must be genetic in the organization. It cannot be viewed by the employees as an option or "just another initiative." The employees will not embrace sustainable lean and the organization will not achieve the expected results without direct involvement. The involvement of every employee at every level of the organization is crucial. No level can be left out, especially middle management or floor supervisors. In the end it's the "people that make the difference" and make the organization function. A key tool for ensuring philosophical alignment and understanding is the Management Operating System, and 5S and Safety.

Throughput Improvement – A anchor of the lean and green implementation is efficient use of resources, or the elimination of waste. In the foundry this efficiency can be achieved through increased throughput of materials. Throughput can be split into eliminating scrap and non-value added activities, increasing productivity through constraint analysis, as well as increasing production efficiency such as casting yield. Improvements in production efficiency can have both a lean and green cascading effect throughout the foundry. Tools and techniques which support throughput include 5S and Safety, Green Value Stream Mapping, Statistical Process Improvement, and the Management Operating System.

Attempts should be made to eliminate not only scrap but also non-value added activities within the casting and finishing processes which can all be considered forms of waste. Castings scrap is pure waste, so efforts to reduce scrap impact the economic and environmental sustainability of a foundry.

Scrapcasting repair and welding are non value added operations and the cost cannot be passed on to the customer. These type of operations are actually waste and should be eliminated from the process. Once the plant floor understands that welding and repairs are no longer accepted by the customer, the foundry can make strides to correct the problems which lead to these issues.

Capacity improvements will also lead to improvements in operating cost, and in energy reductions, as the operating time to produce customer demands is shortened. Lean methodologies can assist in making these productivity improvements. For example, a Canadian aluminum casting plant was able to improve their cylinder block jobs per hour level from 30 to 35 jobs per hour by understanding and eliminating blocked and starved constraints within the manufacturing process. Little additional investment was required to accomplish the task. Costly overtime hours were eliminated because the improved system throughput and on time delivery to the customer were achieved.

Foundries can also focus on casting yield as a specific area for throughput improvement. Yield improvements reduce the amount of material required to produce the product, and the overall energy and material usage for a given customer demand. Yield improvements can occur through improving nearer net shape of casting and increasing the efficiency of the metal feed. If the process can be controlled there will be much less variation and movement in the mold leading to greater near net casting shape. Significant facilities and tooling investment can be reduced in the casting finishing department if the casting processes can be designed and controlled so that they are more repeatable. The metal gating and riser system itself can be viewed as waste, as the gating and riser

system must be removed and is typically recycled through re-melt –an energy intensive process. Optimizing the size and location of risers and the use of efficient gating systems minimize this waste [42]. Significant casting quality improvements have been documented since the utilization of computer simulation solidification models. Computer modeling packages are useful for both gating/rising and mold filling evaluation. Using rice hulls as an exothermic material for an open riser is an example of two lean techniques for the foundry, improving yield, and Beneficially using a waste product. Material reductions within the foundry have impact back to the mining process, reducing the overall life cycle environmental impact

Energy Efficiency– As stated in the introduction, foundries are energy intensive operations. While on site generation of greenhouse gases through the heat generated via the burning of coke or natural gas is a major concern for foundries, data from the U.S. Energy Information Administration Environment website identifies the generation of electricity as the number one source for foundry greenhouse gas emissions. Energy use is typically not

a metric that is employed in manufacturing systems design [25].

Techniques to improve energy consumption used in conjunction with the other waste reduction techniques contained in the lean toolset, not only provide energy reduction, but also improve costs [43]. Tracking energy flows through the system using a Green Value Stream Map is one technique that can be used to reduce consumption. An example is compressed air, often used in foundries. In the UK 10% of the total energy supplied to industry is used to compress air. As little as ten percent of the energy supplied to air compressors can be converted to useful energy [25]. When tracking energy use through the system, minimizing the use of compressed air can improve both cost and environmental impacts. Tracking energy use is vitally important to lean strategies that drive environmental sustainability. Other techniques which can help improve energy usage are Management Operating System, Green Value Stream Mapping, Statistical Process Improvement, and 5S and Safety.

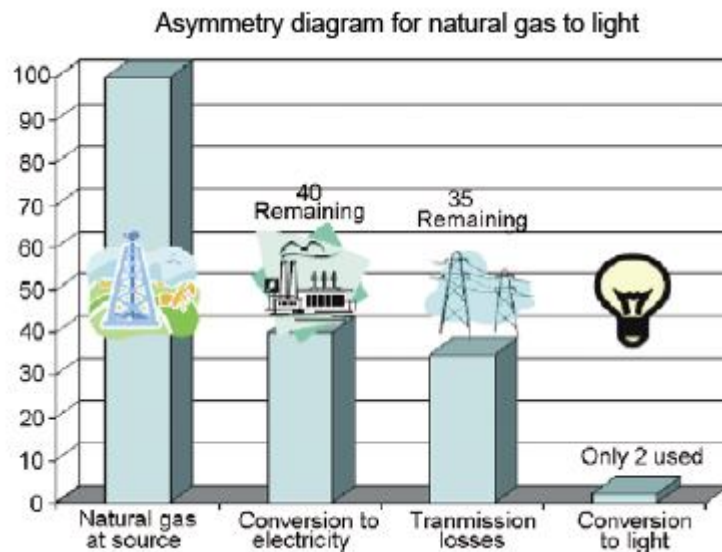


Fig. 8: Losses in net energy from source to sink.

Innovative Technologies - While lean manufacturing techniques can make improvements in a foundry's economic and environmental sustainability, innovative technologies may be required to make large breakthroughs. Emissions requirements have grown considerably more restrictive for foundries with the enactment of the 1990 Clean Air Act [45]. While there are many possible theoretical solutions for reducing foundry emissions, acceptable solutions must also be financially sustainable. To preserve the viability of foundries, both researchers and industry have developed a number of approaches to decrease

emissions from foundries. Strategies range from reformulating chemistries of organic binders to developing processes for conditioning sand to lower the amount of released organic compounds and reduced binder levels by better core blowing. Two specific innovative technologies, Advanced Oxidation and OP-AID, have proven to both improve cost and reduce environmental impacts. Identifying opportunities for innovative technologies can be fostered through the Management Operating System, Green Value Stream Mapping, and 7R

Community Partnerships – While perhaps the

most difficult process improvement, one which has the greatest potential for environmental sustainability is developing community partnerships. Community partnerships can include community outreach activities, partnerships with regulatory agencies, and partnerships with suppliers and adjacent industries. Community outreach can be as simple as activities designed to educate the community surrounding your facility about your efforts to reduce waste. Better still is to take a leadership role in the community environmental efforts such as recycling program leadership. These efforts will improve relations and reduce complaints based on misinformation, and provide a solid footing for your lean efforts.

Many environmental regulation agencies are recognizing that a command and control type of emissions regulations systems are limited in their ability to improve environmental impacts. Some agencies are embracing innovative strategies for environmental stewardship. Most process changes within the foundry will have environmental impacts. Therefore, technical innovation will often require a close partnership with regulatory agencies even if changes reduce emissions or solid wastes at the foundry. A good example of this was Benzene Reduction Action Team formed in Wisconsin between the Wisconsin Department of Natural Resources and a trade organization for Wisconsin metal casting companies which helped these companies meet hazardous air pollutant regulations [46].

Additionally, other manufacturing industries can also become partners if the foundry's system viewpoint is broadened. Many apparent waste products from one industry can be beneficially reused by another. For example, the Portland Cement Association (PCA) of the US and Canada, were able to reduce their emissions considerably in recent years by using alternative materials. They were able to put to use waste materials from the steel and foundry industries, including slag and waste foundry sand [47]. There are many examples of this type of industry synergy. Lean tools which facilitate the discovery of these synergies are Management Operating Systems, Green Value Stream Mapping, and 7R.

The framework described here and its key elements for foundry implementation of lean and green methodologies are just a starting point. Several references are cited in this paper which can provide more in-depth information. 6 Tools, techniques, and technical innovations for lean and green foundries

As earlier stated, lean is a philosophy and not simply a set of tools and techniques. However, some key lean tools and techniques have proven

especially effective in improving foundry sustainability. Figure 9 shows a mapping of these key tools to the elements of a foundry implementation framework. It shows how lean implementation is an integrated system, with several key elements of implementation utilizing many of the same tools or techniques. These include Green Value Stream Mapping, 5S and Safety, Statistical Process Improvement, and 3R. What follows is a brief description of each tool or technique.

Green Value Stream Mapping – A value stream map (VSM) is a simple diagram of the material flow through the system that shows where waste is occurring. One of the best resources for how to create a value stream map is the book "Learning to see" [48]. A value stream map can be constructed for the entire enterprise or for a single production line. While a powerful tool for lean, a VSM typically focuses on the forward product material flow and does not typically consider other material flows and waste streams, especially energy [25]. A Green Value Stream Map (GVSM) includes not only the material flow through the system, but also all of the energy and waste flows. The GVSM process can be used to identify sources of emissions, opportunities for improvement in material and energy usage, non-value added activities, and to provide a roadmap for possible innovative technologies and community partnerships.

key lean tools enabling foundry lean and green implementation framework	Organization philosophy	Improve throughput	Energy efficiency	Innovative technologies	Community partnership
Green value stream mapping		x	x	x	x
5S and safety	x	x	x		
Statistical process improvement		x	x		
7R				x	x
Management operating system	x	x	x	x	x

Fig. 9: Mapping key lean tools to a foundry lean and Green implementation framework

It can also be good communication tools among the stakeholders for all these activities. The technique has been applied effectively to improve both cost and environmental impact. For example, a bicycle manufacturer in China analyzed the flows of water, energy, and solvent pinch in the painting and drying processes independently which then resulted in one process preheating the air intake for the others [25].

In adjoining to looking at just the present flow of material, energy and waste in the system, GVSM can be used to also look at the lifecycle of the product. ISO 14000 provides guidelines for Life-Cycle Assessment (LCA). LCA traces the major steps and processes over the life of a product covering: raw materials extraction, manufacturing, product use, recycling and final disposal. It identifies and quantifies the environmental impacts at each stage [49]. LCA techniques are used extensively in the industrial ecology field which seeks to optimize the life cycle of virgin materials through to ultimate disposal in the pursuit of sustainable manufacturing [25]. Since the prior processing used for many raw materials used by the foundry industry is energy intensive and environmentally sensitive, taking a GVSM life cycle view can demonstrate how improvements in foundry processes have impacts outside of just a specific site. GVSM can also improve communication with community partners, such as regulatory agencies, to gain support for regulatory practices that offer true life cycle improvements rather than just plant-level environmental improvements.

5S and Safety – 5S is an acronym for activities which provide for an ordered workplace in which visual cues can facilitate problem detection and resolution. In English, the 5S's stand for Sort, Straighten, Shine, Standardize, and Sustain. Frequently Safety is included as a sixth 'S' because of its importance to the workers and to the community. Lean manufacturing principles ultimately target the elimination of all forms of waste. The 5S process follows the same philosophy and helps to identify what is waste so that it can be eliminated. A 5S cornerstone is "the right thing in the right place at the right time"; anything else should be disposed of in a safe and environmentally correct manner. When a workplace is implementing 5S, it is very evident to both workers and visitors; providing physical demonstration of the organization's lean philosophy. Maintaining 5S reinforces that management commitment to lean philosophy. 5S is a key element of an overall Management Operating System in that items which need management attention and oversight are blatantly visible to all, fostering the common understanding of what is important. From an environmental sustainability perspective, 5S calls attention to uncontrolled waste and/or emissions because they do not fit the standard. 5S can assist with energy efficiency by calling attention to machines and items which should or should not be running given standard operating procedures. Also, indicators can be developed which visibly show when a system is not operating correctly. A clean floor will quickly show a leak in a system, where material is being wasted. Finally, the 5S process can dramatically change the appearance of a foundry, and can improve the foundry's reputation among

employees (current and prospective) and the community.

Statistical Process Improvement – A key tool supporting lean implementation are probabilistic and statistical methods required to improve the quality of products and processes. Six Sigma methodologies incorporate a toolbox of statistical process improvement (SPI) techniques that can effectively drive sustainable process improvement. It is crucial to identify the true root causes of waste and SPI insures that those root causes and the corrective actions will truly impact those wastes significantly. Statistical Process Control (SPC) Charts can be an important part of both a Management Operating System and the 5S process in the foundry to drive improvements in both process control and environmental control. SPI can be used for reducing foundry scrap with resulting cost and sustainability benefits. Designed experiments can be used to make process improvements as well as environmental improvements. SPI techniques can be powerfully used to develop better understanding of material and energy usage, production line productivity, and environmental impacts. SPC charts can be used for controlling electrical usage, or improving emissions.

7R – Another key thought process or technique is 7R. Originally just 3 R's, which stand for Reduce, Recycle, and Reuse; this mnemonic is a quick reference when looking at materials coming into the system, and wastes leaving the system. These were expanded to 7R's [50], and now include Remove, Renewable, Revenue, and Read. The thought process is simple: can any material in the system create less environmental impact by using any of the 7R's? Can it be removed altogether? Can the usage be reduced? Can the product be reused, or recycled in house or by a partner industry? Can the waste be sold (i.e. revenue)? The last R, read, is to encourage employees and organizations to research the possible uses for their waste materials through reading. A key lean method which supports the 7R technique is 5S because avoiding the mixture of waste streams through clear labeling is helpful. For example, an aluminum foundry machine shop pioneered dry machining techniques which facilitated the re-melting of the aluminum machining chips because they were not contaminated with cutting fluids. Additionally, this same foundry recycled zircon fines, a waste product of their thermal sand reclamation system, to investment casting companies as a raw material. Another example is the beneficial reuse of cupola slag as a material for concrete manufacturers. The value of these materials was improved by the ability to keep them clean and separate from other waste material streams. 7R supports a foundry's ability to form community partnerships and help drive innovation in processes such that the by-products of that process have value.

Management Operating System – While lean is a holistic system for managing any business, the method to manage that system must itself be lean. Thus a lean Management Operating System is crucial to the foundry lean and green implementation framework. Like 5S, and as part of 5S, the Management Operating System hones the requirements to insure operational success just to the crucial items, and discards the rest [51]. The management system is transparent and visible to all of those working and visiting the facility. The process supports the foundry's lean philosophy by insuring that managers and supervisors can 'walk the talk' with a consistent message and consistent performance measures including sustainability measures. A lean management team will determine the key goals for the organization and the measures of success, usually with a process which insures the input of as many people in the organization as possible. This insures buy-in. It is important that the number of metrics is limited, that they are reviewed regularly, and that key metrics, including environmental metrics, are visible to everyone in the organization. It is also important that these measures are consistent and aligned throughout the organization. Ideally, the process reinforces the lean organization philosophy regularly. It measures improvements in throughput at each level of the organization. It includes environmental impacts, such as energy usage and emissions. It asks on a regular basis whether innovative technologies exist to make improvements, and drives partnerships.

7. TECHNICAL INNOVATIONS

To evidence the future for technical innovation to advance the economic and environmental sustainability of foundries, two technologies which have been implemented successfully are described in detail in this section. We describe Advanced Oxidation (AO), which is performed in conjunction with sand conditioning,

Advanced oxidation: A large majority of the foundries in the United States are green sand foundries. Green sand in use generally consists of silica sand, bentonite clay, and carbon additives (usually seacoal), and water. In many cases, the complexity of shapes requires the use of cores. Core sand itself is generally made with sand and some form of curable organic binder as opposed to clay. Core sand requires stronger binding than that of the clay-bound bulk sand to produce acceptable castings, as they generally support more weight per unit area than that of the surrounding green sand. In either case, organic compounds are present in the forms of the resin used and/or the organic compounds contained within the mixtures. Because of the inclusion of these carbonaceous materials, many

reactions occur at high temperatures which can have both positive and negative effects on casting quality and emissions. When pouring ferrous castings at high temperatures, seacoal transforms into a soft formable coke barrier which prevents excessive metal penetration into the mold. The coal also reacts with metal-mold boundary oxygen to form carbon monoxide and other oxygen-rich species, preventing the formation of surface iron oxides. In addition, these gases provide a surface blanket which allows for improved surface finish. However, further from the casting surface, organic compounds in the mold are subjected to cooler temperatures which leave the pyrolysis reactions essentially incomplete [52]. These intermediate temperature reactions lead to release of relatively large amounts of VOC's from both core binder and seacoal decomposition. In terms of core sand, a characterization study revealed that phenols, cresols, benzene and toluene tend to be the main components of pollutant releases in terms of resin binders. In addition, these high temperatures lead to the loss of hydroxyl groups on the surface of the clay, preventing hydrogen bonding, and therefore creating "dead" clay. This dead clay becomes a solid green sand system component that must be removed from the sand system. Additional clay and seacoal must be added to restore the binding properties of the green sand after each molding cycle.

The integration of advanced oxidation (AO) processing into green sand systems represents not only a way to improve emissions, but also to reduce material input and solid waste costs. In the United States, advanced oxidation systems have been installed on 15-20 active green sand production lines, with measured VOC emission reductions from 20%-75% [53]. It is also important to note the use of AO leads to the complimentary reduction of raw material inputs to the green sand system that further reduce sand system VOC emissions. While green sand foundries recycle a great deal of their molding sand, new sand, seacoal and clay must be continually added to make up for breakdown due to continuous cycling through severe conditions. A large green sand foundry (200,000-300,000 tons/year of casting weight) has been estimated to require 50,000 tons of silica sand, 20,000 tons of clay and 6,000 tons of seacoal yearly. AO processing alone allows for a system to retain a significant portion of the useful clay that would normally be exhausted into baghouses and discarded. With the addition of ultrasonic cavitation processing, both baghouse active clay and waste green sand active clay can be reclaimed and material additions can be curtailed [54].

There are three basic designs of AO systems in use. First

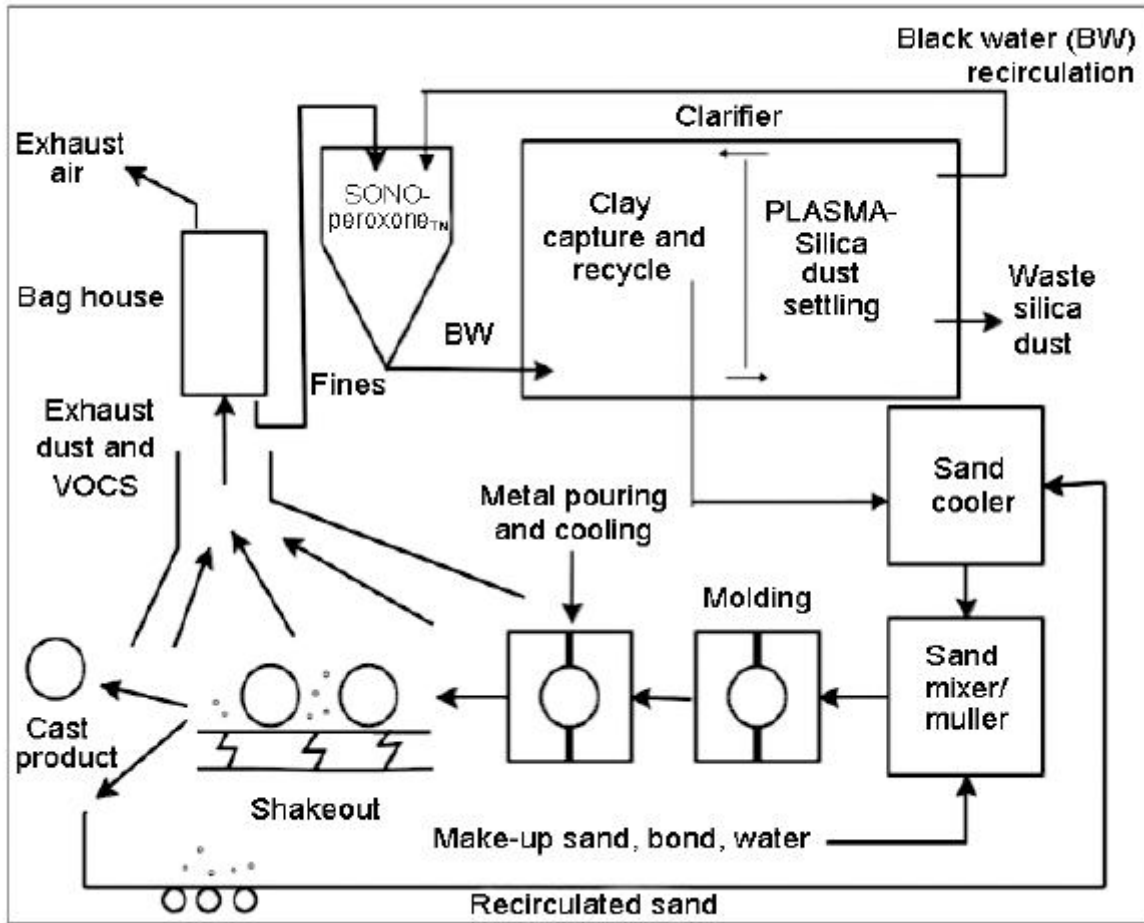


Fig. 10: Simplified model of AO assisted green sand system^[52]

Table 2: AO system performance summary at production iron foundries^[55]

	AO	AO-BW	AO-UCS
Emissions	<ul style="list-style-type: none"> • Benzene emissions reduced 10%-30% • VOC emissions reduced 20%-40% 	<ul style="list-style-type: none"> • Benzene emissions reduced 20%-50% • VOC emissions reduced 30%-75% 	<ul style="list-style-type: none"> • Benzene emissions reduced 20%-50% • VOC emissions reduced 30%-75%
Sand system performance	<ul style="list-style-type: none"> • Clay consumption reduced 15%-35% 	<ul style="list-style-type: none"> • Clay consumption reduced 15%-35% • Blackwater, clarifier active clay recovery improved by an estimated 10%-20% 	<ul style="list-style-type: none"> • Clay consumption reduced 15%-35% • Recovery of 60%-80% of the active clay from sand system baghouse dust
Other benefits	<ul style="list-style-type: none"> • Reduced in-plant smoke and odor from pouring, cooling and shakeout • Reduced stack odor • Reduced ductwork build-up of condensable organic compounds 		

Expected development of AO systems in foundries continues. Ultrasonic cavitation systems (UCS) have been developed to augment early AO system designs. In addition, there is further generation of hydroxylradicals, as the energy from ultrasonic waves has been found to break bonds in peroxide containing water that assist in VOC destruction [56]. UCS systems take up about one fifth of the floor

space as compared to an early AO-BW clarifiers and cost about a quarter of the price. With the addition of ultrasonic cavitation, the amount of bag house dust that can be retained in the slurry can be tripled, leading to increased retained clay and significant reductions in clay additions over early AO- system designs. Furthermore, VOC emissions were further reduced by two-thirds when employing UCS with AO as compared to AO-CW systems [57]. Research

continues in developing AO-UCS systems for not only emissions reduction and bag house dust clay recycling, but also for the purpose of green sand reclamation for use in the core room. For core sand recycling, organic residues left from resins and other bonding media are often stubborn and difficult to remove. Similarly, complete removal of green sand generation advanced oxidation-clear water systems (AOCW) work by treating incoming water with hydrogen peroxide and ozone additions under sonication. This water is then added to sand through mullers and cooling systems for cooling heated sand. Advanced generation systems, which include advanced oxidation dry dust to blackwater (AO-DBW) and advanced oxidation blackwater from wet collector systems (AO-BW-WC) work with particulate collection systems to return a portion of "useful" clay which remains trapped in baghouse fines and waste green sand. In traditional non-AO systems, active clay contained within these fines remains trapped due to a hydrophobic organic coating acquired during the high-temperature processes of casting. During AO processing these dry fines collected from bag house dust and/or wet collection sludge are combined with water to form what is called "blackwater." This blackwater is then AO-treated, and hydroxyl and other electronegative ions react with the organic coatings. The water is then sent to a settling tank where inactive fines settle, leaving AO-treated blackwater with active clay to return to the system, preserving active clay. With an optimized AO system, pre-bond additions have been reduced by 25%, while green strength has increased a small but significant amount at the same time [55]. Clay and carbonaceous coating for re-bonding in the core room is very challenging. The traditional methods of reclamation are often energy and capital intensive. For example, thermal reclamation systems heat sand between 500-800°. Not only are large amounts of heating energy required, but valuable clay is destroyed as both calcium and sodium bentonite degrade at temperatures between 450-620°. Traditional wet reclamation methods require large amounts of water, large amounts of floor space, and inadequately remove clay and other organics from sand [57-58].

Utilizing AO-UCS systems, MB clay on reclaimed green sand was reduced from 7.92% to 0.4% 0.6%. LOI was reduced similarity from 3.8% to 0.4%-0.6%. With a 60% AO-UCS reclaimed mix to 40% new sand mixture used in core making with conventional PUCB binders and binder levels, core tensile strengths of about 120 psi were reached. In addition, the size distribution of sand for processing can be adjusted through AO-UCS process parameters, so that reclaimed sand can be used for core sand and/or returned to the green sand system in place of new make-up sand [58].

7. CONCLUSIONS

This paper provides a broad perspective on combining lean manufacturing methods with environmental sustainability to assist foundries in remaining competitive. Two specific technologies which both improve cost and reduce environmental impact for foundries were reviewed, demonstrating that environmentally sustainability solutions can also reduce foundry operating costs. A set of proven, effective lean tools and techniques that can assist foundries in their sustainability efforts were reviewed. These tools are part of a proposed framework of key elements for foundries implementing a combined lean and green strategy for sustainable success. This framework identifies key process improvement efforts for foundries, including improving throughput, energy efficiency, innovative technology, and community partnerships. These process improvement efforts are supported by a pervasive organizational philosophy for lean / waste reduction. A review of lean/sustainability practices in the foundry industry and other industry sectors demonstrates there is a positive synergy between lean efforts and environmental sustainability. While implementing a lean manufacturing system does not lead to environmental sustainability, including environmental and other sustainability components within a lean system improves a company's ability to make continuous improvements in both cost and environmental impacts. This synergy between lean and green efforts provides the foundry industry a clear pathway and framework to become economically and environmentally sustainable.

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NUMERICAL SIMULATION OF TEMPERATURE DISTRIBUTION AND ELECTRIC FIELD ANALYSIS OF MICRO ELECTRICAL DISCHARGE MACHINING PROCESS

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Abstract-A simulation strategy of a micro Electrical Discharge Machining (micro-EDM) process using a Finite Element Analysis (FEA) has been developed. To model precisely the several stages of a crater formation by a single EDM discharge a multiphysics model has been developed. Then, to simulate the formation of a machined surface composed of several craters simulation of a series of the crater formation was conducted. The developed multiphysics FEA model is composed of electric field, thermal, and deformation analyses, and has been implemented using a commercial software package. The electric field analysis is conducted to check whether the EDM spark can be generated and to determine the spark location. Especially, the electric field analysis has been used to determine subsequent spark location during the EDM process. For the thermal analysis expanding plasma channel model with Gaussian heat input distribution was used. The phase changes from solid to liquid and from liquid to vapor were considered in the calculations. The information on boiled and molten region of the workpiece determined from the thermal analysis was used in the deformation simulation. To check the validity of the proposed FEA strategy, a crater generated by real micro-EDM machine was compared to the simulation result.

Keywords: EDM simulation, crater, multiphysics simulation

1. INTRODUCTION

Micro electrical discharge machining (Micro-EDM) is one of promising technology to produce micro products. EDM is a machining process using the electrical discharge sparks between the two electrodes (tool and workpiece). Therefore, various electrical parameters as well as the material properties are involved in determining the process characteristics. However, selection of optimal machining parameters is difficult because the EDM process affected by the various electrical parameters is not clearly identified yet. Precise simulation of machining process enables better understanding of material removal mechanism, selection of optimal machining parameters, and prediction of the machined surface quality. Especially, because the material removal mechanism of EDM is difficult to observe directly the use of simulation becomes an important tool to acquire the detailed knowledge of the process. [1, 2] In this study, a simulation model of micro-EDM process has been developed. To calculate the machined surface property, such as the depth of melting layer and machined surface morphology, an iterative multiphysics EDM model is implemented to Finite Element Analysis (FEA). The developed model is used to predict the surface modifications by multiple discharges. In Section 2 the multiphysics simulation model is introduced. In Section 3 the details of the simulation steps are introduced and the results are compared to the experiment results. To verify the simulation result, focused ion beam analysis of real EDM machined surface was used.

2. MULTIPHYSICS SIMULATION OF AN EDM PROCESS

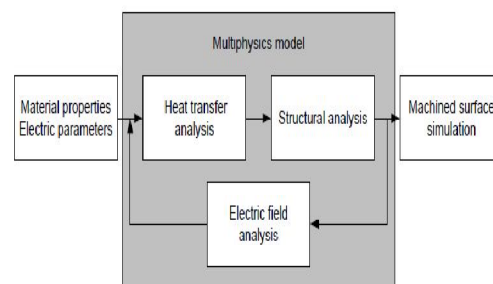


Fig. 1 Multiphysics model for EDM simulation

Figure 1 shows the proposed multiphysics simulation model of an EDM process composed of three sequential steps: (1) Heat transfer analysis step, (2) Structural analysis step, and (3) Electric field analysis step.

The heat transfer analysis step calculates the temperature distribution generated by plasma heat source between the tool electrode and the workpiece. In the developed model, expanding plasma channel model with Gaussian heat input distribution proposed by Yadav et al. [3] and Shuvra Das et al. [4] has been used to calculate the molten and boiled part of the workpiece. In the model the heat source (which is a constant fraction of total electrical energy [5, 6]) has a Gaussian distribution expanding as a function of time. [7]

The structural analysis step identifies and removes the vaporized part, and adjusts the material properties of the molten part of the workpiece. Then, crater deformation under the high pressure plasma is

calculated. The pressure of discharge plasma is based on a model by Eubank et al. [8]

During electric field analysis step, the subsequent spark ignition location is calculated using the modified surface geometry as a result of the structural analysis.

The proposed process model has been applied to simulate multiple discharges. The three steps in the model complete a single cycle of each discharge and crater formation. Actual machined surface can be predicted by the iteration of the cycle. The developed model has been implemented using a commercial software package (ANSYS). The element size was $1\mu\text{m} \times 1\mu\text{m}$.

3. SIMULATION RESULTS

3.1 Simulation of white layer formation

The white layer is the recast layer which is generated by the heat of discharge plasma. Therefore, the white layer thickness can be calculated in the heat transfer analysis by measuring the thickness of molten layer. The temperature distribution generated by the single discharge spark can be calculated using the heat source model in heat transfer analysis step. Figure 2 shows the result of heat transfer analysis of a SKD11 workpiece. The discharge voltage was 25V, the peak current was 12A and the pulse duration time was 1.8 μsec .

The melting and boiling point of SKD11 is about 1800K and 3100K, respectively. Because the plasma pressure is much higher than the atmospheric pressure, the boiling point at the plasma pressure is higher than the boiling point at the atmospheric pressure. At the high pressure, the melting region is known to be removed as result of the plasma flushing effect instead of vaporization. [5] However, because obtaining the plasma flushing coefficient from experiment is difficult, in the proposed model it is assumed that region where the temperature exceeds predetermined temperature is removed by plasma flushing. In this model the region which exceeds the boiling point at atmospheric pressure has been removed. The molten region is remained and built up the white layer. In the Fig. 3, the region which has temperature distribution 1800K - 3100K can constitute the white layer. The white layer thickness on the center of crater is about $1.5\mu\text{m}$ because the mesh size is $1\mu\text{m}$.

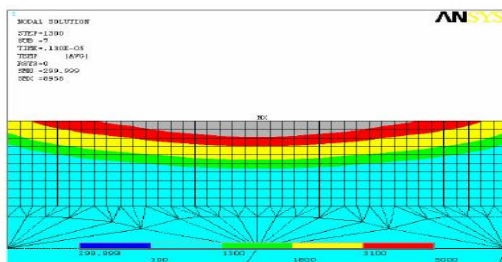
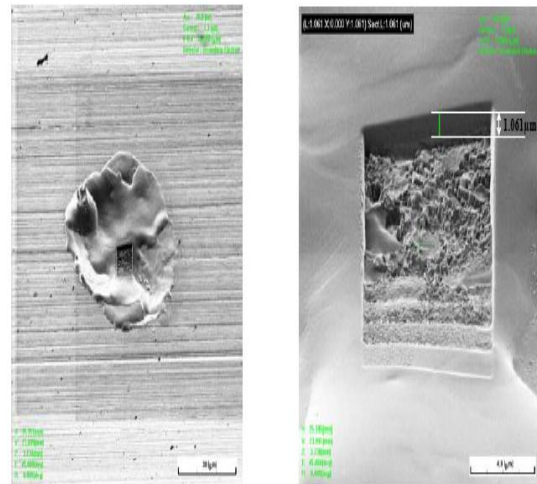


Fig. 2 Result of heat transfer analysis



(a) Single discharge crater

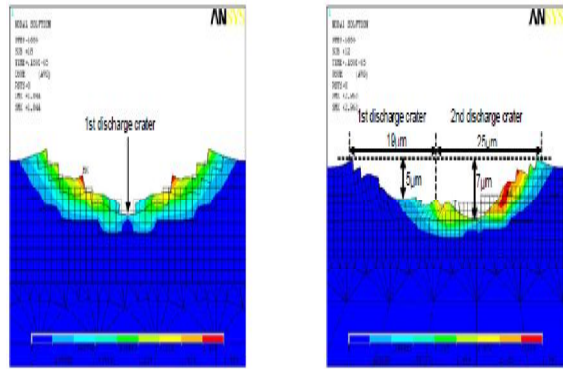
(b) the section on the crater

Fig. 3 White layer measurement on the single discharge crater

The white layer of single discharge crater was measured. A Focused Ion Beam (FIB) microscope (SMI-2050, SII Nanotechnology) analysis has been used to measure the white layer structure. Figure 3 displays the FIB images of white layer in a single discharge crater. After the crater formation, the white layer has different microstructure from the original metal microstructure. [9, 10] By measuring the cross section of the crater, the crater could be compared with the simulation result. The single discharge crater was ion-milled to compare metal microstructure at the different depth from the crater surface. The original metal grain was not observed on the machined surface. When the ion-milling depth was increased, the original metal grain appeared. Figure 3 (b) is image of the section on the single discharge crater. The measured thickness of white layer was about $1.1\mu\text{m}$. As can be seen the simplified method to simulation plasma flushing worked well. However, more precise calculation of the flushing effect may be implemented in the further research.

1. 3.2 Sequential discharge behavior simulation by multiphysics approaches

The multiphysics model was applied to simulate the sequential discharge behavior. After the heat transfer analysis step, the boiling part is removed and the material properties are modified according to the temperature distribution. During the structural analysis step the pressure is applied on the workpiece and the crater shape is generated. Figure 4 (a) shows the result of the single discharge crater simulation after the structure analysis step.



(a) Single crater deformation

(b) Sequential craters deformation

Fig. 4 Results of structural analysis

Electric field analysis is conducted using the crater topology and the electrode location information. Figure 5 shows the result of electric field analysis. The electric field analysis calculates the electric field strength in the dielectric fluid between electrode and workpiece. The upper side is electrode and the bottom is the crater on the workpiece. Assuming that the shape of electrode surface is flat or a point, the electric field strength is dependent on the crater topology. As can be seen in the figure, the position which has maximum electric field strength is on the ridge of the crater, so the next ridge of the crater can be considered as the next discharge point.

Once the next discharge point is determined in the electric field analysis, the second crater generation simulation is conducted following the same process as the first cycle of the simulation. The heat flux is transferred into deformed surface and the crater generation on the deformed surface is simulated. Figure 4 (b) shows the result of the second crater generation simulation.

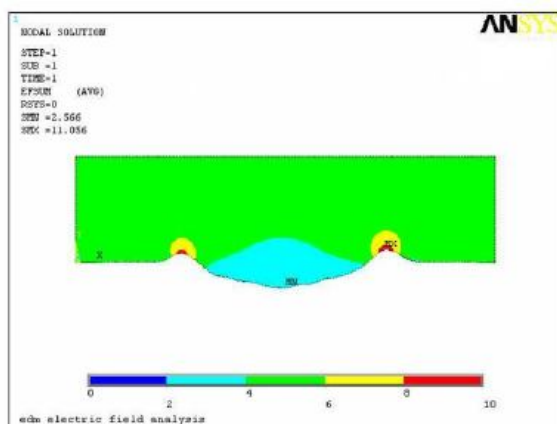
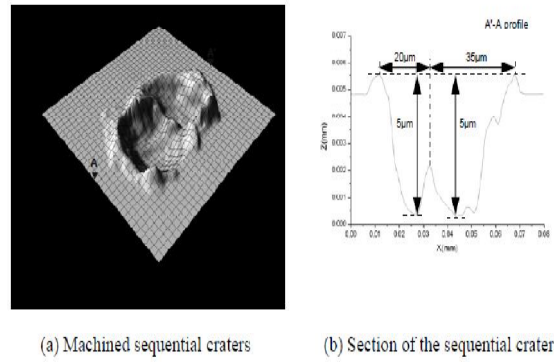


Fig. 5 Result of electric field analysis



(a) Machined sequential craters

(b) Section of the sequential craters

Fig. 6 Result of measuring the sequential craters

To compare the simulation result with real multi crater geometry, a surface generated by two sequential discharges was measured by white light interferometer microscope (Nanoscan, Nano Systems). Figure 6 (a) shows the image of the machined surface and (b) shows the section of the crater. As can be seen in Fig. 4 (b) and Fig. 6 (b), the distance between the two craters and the geometry of the crater matched well with the simulation results.

4. CONCLUDING REMARKS

In this study, a multiphysics simulation strategy to predict a property of micro-EDM machined surface has been proposed. The multiphysics model was consisted of three steps, and these three steps were iterated for sequential discharge simulation. The temperature distribution in workpiece was calculated in heat transfer analysis step and the proposed approach was applied to the prediction of the white layer thickness. To measure the white layer thickness on single discharge crater, ion-milling using FIB was proposed. For simulating the crater geometry as a result of multiple discharges, the multiphysics model was iterated. The subsequent discharge point was determined as a result of electric field analysis and the same heat source and plasma pressure transferred into the deformed surface. The simulation results were compared to the experiment results and demonstrated that simulation results gave a good predicted values. The analysis results can be utilized to the prediction of surface roughness and geometry of the micro-EDM processes.

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