International Journal of Mechanical and Industrial Engineering

Volume 2 | Issue 4 Article 9

April 2013

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SATHISH KUMAR N
Technology Centre, Kennametal India Ltd., Bangalore, India, sathish.kumar3@kennametal.com

PADMAKUMAR M
Technology Centre, Kennametal India Ltd., Bangalore, India,
padmakumar.muthuswamy@kennametal.com

Recommended Citation

N, SATHISH KUMAR and M, PADMAKUMAR (2013) "AN EXPERIMENTAL STUDY OF APPLYING VARIOUS CUTTING EDGES ON WIPER MILLING INSERTS IN FACE MILLING AISI 1070 STEEL," *International Journal of Mechanical and Industrial Engineering*: Vol. 2 : Iss. 4 , Article 9.
DOI: 10.47893/IJMIE.2013.1107
Available at: https://www.interscience.in/ijmie/vol2/iss4/9

AN EXPERIMENTAL STUDY OF APPLYING VARIOUS CUTTING EDGES ON WIPER MILLING INSERTS IN FACE MILLING AISI 1070 STEEL

SATHISH KUMAR N & PADMAKUMAR M

Technology Centre, Kennametal India Ltd., Bangalore, India
Email: sathish.kumar3@kennametal.com, padmakumar.muthuswamy@kennametal.com

Abstract: - In metal cutting industry, edge preparation on carbide inserts have a significant effect on the productivity of a machine. In this study, the effect of various cutting edge preparations on wiper facet which influences various force components and surface finish in the rough milling operation of AISI 1070 steel were experimentally investigated. Tungsten Carbide inserts with three distinct edge preparations and AISI 1070 steel blocks were used. Three-factor (Cutting speed, Feed and Geometry), three-level full factorial design experiments were conducted under dry conditions. During the rough milling operation, three components of forces and surface finish of the machined surface were measured. This study shows that the effect of various edge geometries is more significant on surface finish and has very little impact on the force components.

Keywords: *milling insert; edge preparation; wiper facet; cutting force; surface finish.*

1. INTRODUCTION

Milling process is the second most common metal cutting (after turning) operation especially for the finishing of machined parts. In modern industry the goal is to manufacture low cost, high quality products in short time [1].

Metal cutting is a process in which a wedge-shaped cutting tool engages the work piece to remove a layer of material in the form of a chip. The following principles are required to fully understand the metal cutting process.

1. How tools cut (geometry),
2. Grade (cutting edge materials),
3. How tools fail, and
4. The effects of operating conditions on tool life, productivity, and cost of work pieces [2].

The term edge preparation, as applied to a cutting tool, is a modification of both rake and clearance surfaces. Edge preparation enhances tool life but at the same time makes cutting less efficient especially when the ratio of uncut chip thickness to tool edge radius decreases. So selection of optimum edge geometry is important. Edge preparation is applied to the cutting edge of a tool for three primary reasons,

1. To strengthen the cutting edge and reduce the tendency for the cutting edge to fail by chipping, notching, and fracture.
2. To remove the minute burrs created during the grinding process.
3. To prepare the cutting edge for coating by the chemical vapor deposition (CVD) process [2].

The quality of the surface has a very important role in the performance of face milling because a good quality machined surface significantly improves fatigue strength, corrosion resistance and creep life [3].

Proper edge preparation is essential to increase the strength of cutting edge and attain favorable surface characteristics on finished metal components [4].

This discussion will concentrate on various edge preparations in a Tungsten Carbide insert and its effect on the metal cutting process (Force and Surface finish of the workpiece). Edge preparation generally falls into four categories. They are sharp edge, honed radius, T-landed (also called as chamfered edge) cutting edge and combination of T-land + honed radius [2].

1.1 Sharp Edge

Sharp edge (shown in fig.1.a) is produced when no edge preparation is done on the cutting edge of the insert and left sharp. The cutting edge on a carbide or ceramic cutting tool is never "sharp" unlike a HSS cutting edge. As carbide is a highly brittle when compared to HSS, the sharp edge will break easily when the tool is cutting.

1.2 Hone Radius

The honing process produces a radius on the cutting edge of the insert. This hone radius (shown in fig.1.b) strengthens the cutting edge by directing the cutting forces through a thicker portion of the cutting tool.

1.3 T-Lands

T-lands (shown in fig1.c) are chamfers machined onto the cutting edge, which produce a change in the effective rake surface of the cutting tool. These chamfers, which make the rake surface more negative, are designed with a specific width and angle.

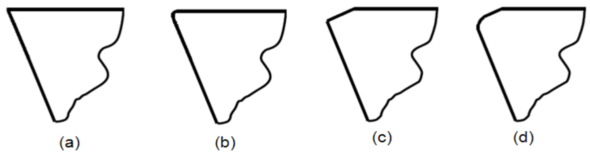
The chamfered/honed tool is recommended to prevent the chipping of the cutting edge and to impart strength to the cutting edge [5].

1.4 T-Land + Honed radius

This type of edge preparation is a combination of both T-Land and honed radius (shown in fig.1.d). This gives the advantage of both the edge preparation types, T-Land and Honed Radius [2].

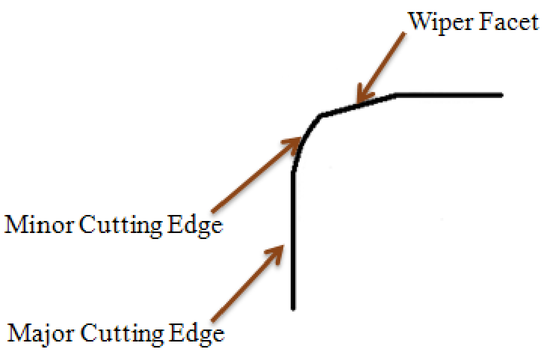
1.5 Wiper Facet

The function of wiper facet (shown in fig. 2) is to rub the work-material and not to cut. This facet is incorporated in an insert to get good surface finish. The wiper facet on the insert creates added tool pressure. This is due to the slightly higher cutting forces wiper facet generates, compared to a standard radius insert. A general rule to follow is wiper inserts will generate nearly twice as much tool pressure as standard inserts which gives extra finish to the workpiece being machined [6].



(View on cutting edge normal to plan P_n)
(a) Sharp Edge (b) Honed radius
(c) T-Land (d) T-Land + Honed radius

Fig. 1. Various cutting edge geometries



(View on the tool reference plane P_r)

Fig. 2. Cutting edge and Wiper facet

1.6 Forces involved in milling

Cutting force and their moments have significant importance in engineering technology; generally in the theory of material machining. They represent the basic categories of cutting mechanics. It is commonly known that during the metal cutting process, the tool geometry changes as a result of tool wear and that these changes can have undesirable effects on process performance. The most significant variation is increase in cutting forces, which can lead to variations in process stability, part accuracy and part surface finish [1].

Face milling process is a multi-tooth interrupted cut machining operation. Variation in chip cross section during the cutting gives difference in intensity of cutting forces and thermal load on single tooth [7]. Fig 3 shows the various forces acting on the tool during the face milling operation such as feed force (F_x), cutting force (F_y) and thrust force (F_z). Among the three forces the cutting force value is the maximum and is of high importance as it affects the tool life and power consumption.

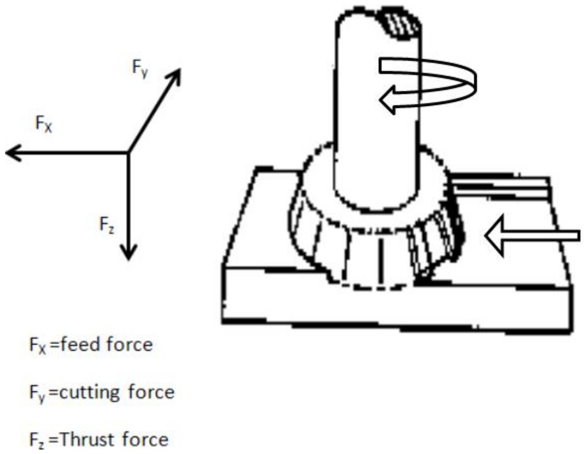
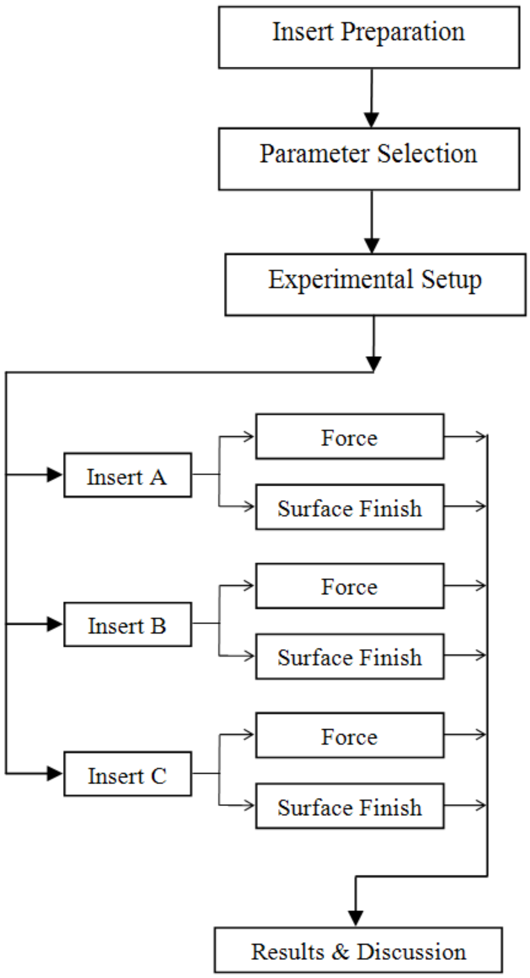


Fig. 3. Forces involved in face milling

2. PROPOSED METHODOLOGY



3. EXPERIMENTAL PROCEDURE

The experimental setup is arranged as shown in figure 5. The workpiece used is an AISI 1070 steel block. The steel block is prepared in such a way that it can be mounted on the dynamometer (KISTLER 9256). The dynamometer was mounted atop the machine table and beneath the workpiece, as shown in Fig. 6. The electrical signals from the dynamometer were transformed into numerical signals by an A/D converter. The numerical signals to measure the cutting force were displayed and saved on the computer using data acquisition software.

Insert A is loaded on the milling cutter such that edge 1 does the cutting. Cutting speed and feed are taken as 70m/min and 0.1mm respectively for the edge 1. Depth of cut is maintained at 2mm throughout the experiment. During the cutting operation, the force components F_x, F_y and F_z are measured directly from the dynamometer. Once the first pass got completed, surface finish was measured with the portable surface finish measuring device, Mitutoyo-SJ201 as shown in figure 7, which allows measurements in microns. Now the Insert is indexed so that edge 2 does the cutting with the parameters cutting speed and feed as 70m/min, and 0.15mm respectively. The process is repeated for the remaining edges with parameters as shown in the table. Only one edge is used for each different parameter.

3.1 Various edge preparations

Edge preparation must be carefully selected for a given application because it affects the surface integrity of the machined workpiece [8]. The figure 4 shows the various cutting edge preparations done on the inserts for the experimental purpose.

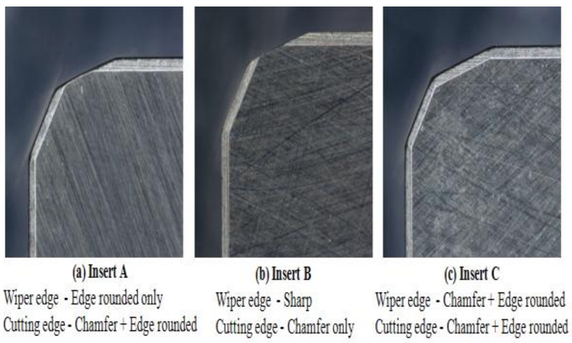


Fig. 4. Various cutting edge preparations

Chamfer is machined in the cutting edge with a computer controlled grinding wheel and edge round is produced with edge rounding machine which uses nylon brush. Edge round value is maintained between 40 to 50 µm and chamfer with 20^{o} inclination and 0.2 mm width.

4. CUTTING CONDITIONS

Table 1. Cutting conditions used

Cutting Conditions			
Parameter	***Detail***	***Parameter***	***Detail***
V_c (m/min)	70/90/110	Coolant	Dry (No Air)
f (mm)	0.1/0.15/0.2	Work piece	EN19
(Ap),mm	2	Tool diameter (mm)	Ø80
(Ae),mm	50	Milling Machine	Mazak FJV-200
Number of teeth	1 (Fly cut)	Insert Coating	Uncoated
Radial Rake Angle	3.5°	Axial Rake Angle	8.5°
Lead Angle	15°	Insert Relief Angle	11°

Fig. 5. Milling machine setup

Fig. 6. Workpiece clamped to dynamometer fixture

Fig. 7. Surface roughness measurement

5. RESULTS AND DISCUSSIONS

The purpose of the statistical analysis of variance (ANOVA) is to investigate which design parameter significantly affects the surface roughness and flank wear. Based on the ANOVA, the relative importance of the machining parameters with respect to surface roughness and flank wear was investigated to determine the optimum combination of the machining parameters.

The sources with a Probability level less than 0.05 are considered to have a statistically significant contribution to the performance measures [9].

S. No.	V_c, m/min	f, mm/teeth	A_p, mm	Insert A	Insert B	Insert C
1.	70	0.1	2	1.61	0.45	1.26
2.	70	0.15	2	1.51	0.66	1.48
3.	70	0.2	2	1.63	0.99	1.14
4.	90	0.1	2	1.63	0.50	0.98
5.	90	0.15	2	1.43	0.57	1.21
6.	90	0.2	2	1.41	0.42	0.83
7.	110	0.1	2	1.58	1.21	1.16
8.	110	0.15	2	1.53	0.49	0.93
9.	110	0.2	2	1.19	0.62	0.82

Table 2. Surface finish values

From the figures 8 & 10, main effect plot and ANOVA of surface finish, it can be observed that geometry alone has significant effect on the surface finish for the selected cutting speed and feed range.

From the figures 11 & 13, main effect plot and ANOVA of feed force, it can be observed that cutting speed, feed and geometry has significant effect on the feed force.

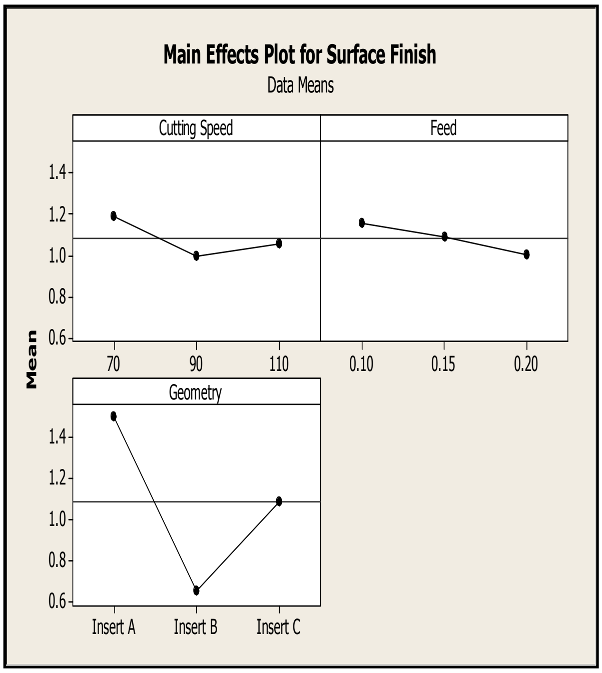


Fig. 8. Main effect plot for Surface finish

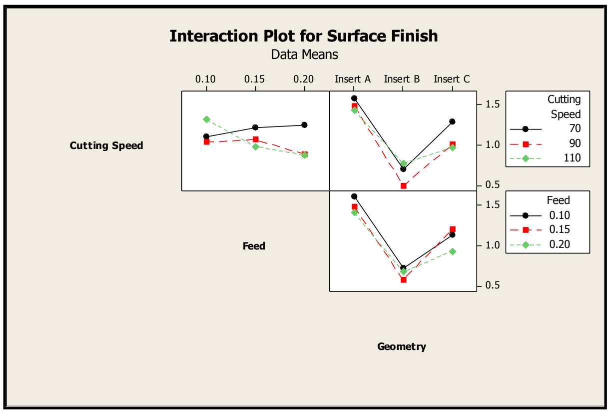


Fig. 9. Interaction plot for Surface finish

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Analysis of Variance for Surface Finish, using Adjusted SS for Tests

Source                  DF   Seq SS   Adj SS   Adj MS      F      P
Cutting Speed            2  0.17796  0.17796  0.08898   2.85  0.116
Feed                     2  0.09894  0.09894  0.04947   1.59  0.263
Geometry                 2  3.21801  3.21801  1.60900  51.60  0.000
Cutting Speed*Feed       4  0.30933  0.30933  0.07733   2.48  0.128
Cutting Speed*Geometry   4  0.16779  0.16779  0.04195   1.35  0.333
Feed*Geometry            4  0.11708  0.11708  0.02927   0.94  0.489
Error                    8  0.24945  0.24945  0.03118
Total                   26  4.33856
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Fig. 10. ANOVA for Surface finish

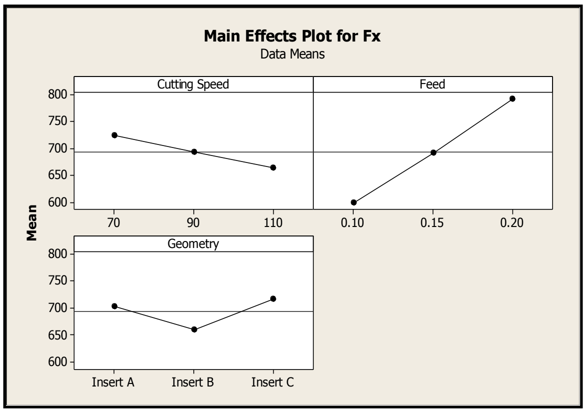

Fig. 11. Main effects plot for Feed force

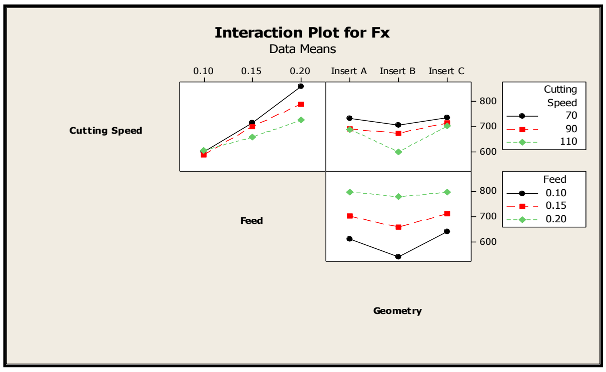

Fig. 12. Interaction plot for Feed force

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Analysis of Variance for Fx, using Adjusted SS for Tests

Source                  DF  Seq SS  Adj SS  Adj MS      F      P
Cutting Speed            2   16892   16892    8446   6.32  0.023
Feed                     2  167805  167805   83903  62.80  0.000
Geometry                 2   16415   16415    8208   6.14  0.024
Cutting Speed*Feed       4   15074   15074    3768   2.82  0.099
Cutting Speed*Geometry   4    6410    6410    1603   1.20  0.382
Feed*Geometry            4    5108    5108    1277   0.96  0.481
Error                    8   10689   10689    1336
Total                   26  238394
```

Fig. 13. ANOVA for Feed force

Table 3. Feed force values

S. No	V_c, m/min	f, mm/teeth	A_p, mm	Insert A	Insert B	Insert C
1.	70	0.1	2	633.28	554.74	611.94
2.	70	0.15	2	720.46	700.05	727.68
3.	70	0.2	2	842.25	863.03	869.36
4.	90	0.1	2	600.6	562.89	603.27
5.	90	0.15	2	704.02	664.91	729.78
6.	90	0.2	2	765.63	793.65	810.59
7.	110	0.1	2	597.11	508.65	555.89
8.	110	0.15	2	684.08	610.51	680.83
9.	110	0.2	2	786.23	679.32	712.41

From the experimental results (Tables 3, 4 & 5), it is observed that for increase in cutting speed, the cutting force shows an increasing trend in magnitude than the other force components.

From the figures 14 & 16, main effect plot and ANOVA of cutting force, it can be observed that cutting speed and feed alone has significant effect on the cutting force.

Table. 4. Cutting force values

S. No.	V_c, m/min	f, mm/teeth	A_p, mm	Insert A	Insert B	Insert C
1.	70	0.1	2	738.1	704.6	722.7
2.	70	0.15	2	921.7	906.7	897.9
3.	70	0.2	2	1062.6	1078.7	1096.0
4.	90	0.1	2	690.7	673.7	683.3
5.	90	0.15	2	849.8	831.6	843.8
6.	90	0.2	2	1012.1	1016.1	1057.4
7.	110	0.1	2	665.0	614.1	660.0
8.	110	0.15	2	832.8	849.1	873.4
9.	110	0.2	2	1014.9	961.2	980.9

Table. 5. Thrust force values

S. No.	Vc, m/min	f, mm/teeth	A_p, mm	Insert A	Insert B	Insert C
1.	70	0.1	2	246.55	220.77	234.33
2.	70	0.15	2	291.32	261.79	263.54
3.	70	0.2	2	298.88	283.5	293.25
4.	90	0.1	2	226.13	203.19	214.31
5.	90	0.15	2	249.42	224.54	234.1
6.	90	0.2	2	227.9	255.23	291.29
7.	110	0.1	2	231.33	178.7	204.49
8.	110	0.15	2	243.73	234.33	259.32
9.	110	0.2	2	263.76	229.01	263.25

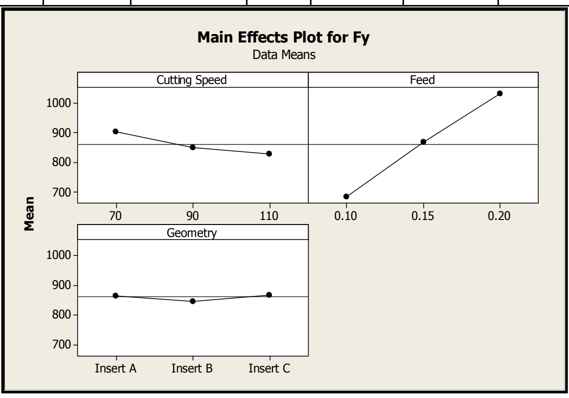

Fig. 14. Chart for Cutting force at various parameters

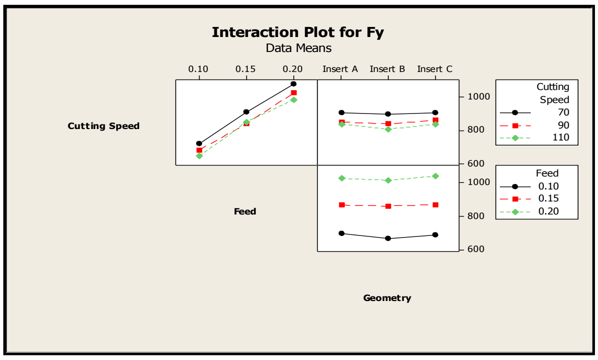

Fig. 15. Interaction plot for Cutting force

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Analysis of Variance for Fy, using Adjusted SS for Tests

Source                 DF   Seq SS   Adj SS   Adj MS       F      P
Cutting Speed           2    26791    26791    13395   32.20  0.000
Feed                    2   544098   544098   272049  653.87  0.000
Geometry                2     2074     2074     1037    2.49  0.144
Cutting Speed*Feed      4     2713     2713      678    1.63  0.258
Cutting Speed*Geometry  4      549      549      137    0.33  0.851
Feed*Geometry           4      911      911      228    0.55  0.707
Error                   8     3328     3328      416
Total                  26   580464
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Fig. 16. ANOVA for Cutting force

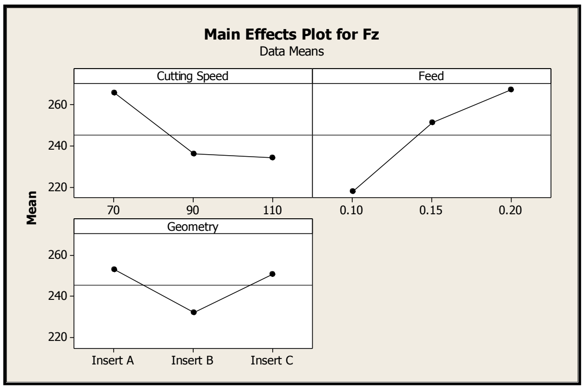

Fig. 17. Main effects plot for Thrust force

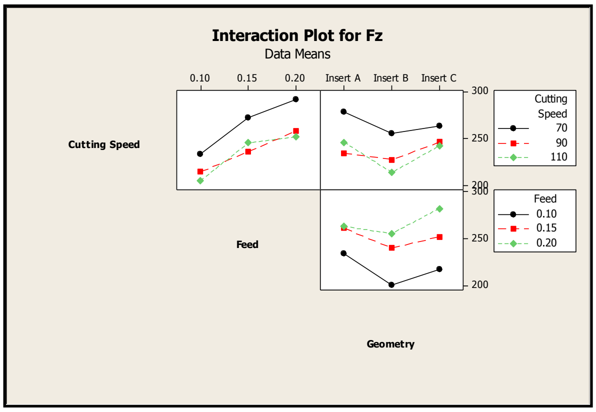

Fig. 18. Interaction plot for Thrust force

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Analysis of Variance for Fz, using Adjusted SS for Tests

Source                  DF   Seq SS   Adj SS   Adj MS      F      P
Cutting Speed            2   5699.4   5699.4   2849.7  13.73  0.003
Feed                     2  11529.3  11529.3   5764.7  27.77  0.000
Geometry                 2   2356.0   2356.0   1178.0   5.67  0.029
Cutting Speed*Feed       4    482.6    482.6    120.7   0.58  0.685
Cutting Speed*Geometry   4    910.1    910.1    227.5   1.10  0.421
Feed*Geometry            4   1173.0   1173.0    293.3   1.41  0.313
Error                    8   1660.7   1660.7    207.6
Total                   26  23811.2
```

Fig. 19. ANOVA for Thrust force

From the figures 17 & 19, main effect plot and ANOVA of thrust force, it can be observed that cutting speed, feed and geometry has significant effect on the thrust force.

6. CONCLUSION

In this work, a detailed experimental investigation is done for the effect of various cutting edges on wiper milling inserts in face milling was conducted and Minitab 16 is used to obtain main effect plots, interaction plots and ANOVA table. Based on the experimental and analytical studies following conclusions have been made:

- Based on main effect plots and ANOVA table, it is observed that the cutting speed and feed has less impact on surface finish; but edge geometry has the highest influence for the selected cutting conditions. Among the three edge geometries, Insert B (chamfer with sharp) gives the best surface finish value.
- It is also found that,
  - Cutting speed and feed has the most significant effect on the cutting force when compared to edge geometry for the selected cutting conditions. As the cutting speed increases, cutting force decreases, but increase in feed increase the cutting force. This is due to the increased thermal softening of the work material at higher cutting speed.
  - Cutting speed, feed and geometry has significant effect on the feed force and thrust force for the selected cutting conditions.

7. FUTURE WORK

1. Tool life and chip formation mechanism can be analyzed for the same edge preparations.
2. The experimental study can be compared with Finite Element Analysis.
3. The same edge geometry can be tested on the wiper insert for force and surface finish measurements.

8. ACKNOWLEDGMENT

The authors express their sincere thanks to all employees of Kennametal India Ltd., who assisted in completing this research work successfully.

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9. NOMENCLATURE

V_c - Cutting speed (m/min)

f - Feed (mm/tooth)

A_p - Axial depth of cut in mm

A_e - Radial depth of cut in mm

R_a - Average surface roughness (μm)

F_x - Feed force (N)

F_y - Cutting force (N)

F_z - Thrust force (N)

P_n - Cutting edge normal plane, a plane perpendicular to the cutting edge at the selected point on the cutting edge [10].

P_r - Tool reference plane, a plane through the selected point on the cutting edge, so chosen as to be either parallel or perpendicular to a plane or axis of the tool convenient for locating or orienting the tool for its manufacture, sharpening and measurement [10]. In this paper it is on rake face.

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