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EXPLORATION THE EXTRUDABILITY OF ALUMINUM MATRIX COMPOSITE (LM6/TIC) THROUGH MODELING, SIMULATION AND EXPERIMENTAL PROCESS

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ABSTRACT

Aluminum matrix composites (LM6/TiC) is a mix of excellent properties of aluminum casting alloy (LM6), and particles of (TiC) which make it the first choice in many applications like airplane and marine industries. During this research the extrudability and mechanical specifications of this composite (LM6/TiC) are investigated before and after extrusion theoretically and experimentally. In this research; ABAQUS/CAE software has been successfully employed for Modeling and simulation the extrusion process before experiments in order to predict any error before fabrication. The experimental works includes design and fabrication the extrusion mold. The extruded parts are test by (SEM) to show the microstructure properties. Simulation results indicate the positions of stresses concentration (Mises stresses), and also the velocity of dislocation elements during extrusion. Experimental results show that, many mechanical properties are improved and enhanced after extrusion like stiffness and wear resistance. The microstructure test show that, the addition of (5%) wt. of (TiC) particulate with (T6) heat treatment (treating the solution in (525°C) and then ageing for (8) h at 180 °C) to the master alloy (LM6) will improve the strength about more than (15%) comparing with original matrix (LM6).

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Comparison between theoretical and practical results before and after extrusion indicates significant improvements after adding (TiC) particulates. This improvement is due to the high interference and bonding forces between the master alloy and composite particulates, which result in a fine grain size after the process.

Keywords: Aluminum, Extrusion, Composite, TiC, LM6.

1. INTRODUCTION

One of the important mechanical processes for mass production is extrusion process. Many final and semi-final products can produce by this process. Extrude any metal will basically depend on its extrudability. Aluminum is one of the important metal which can easily extrude to many shapes according to its mechanical and physical properties [1]. Aluminum metallic matrix (LM6) is the matrix in this product, while titanium carbide particulate (TiC) elements as an isolated spherical or needle particles. Homogeneous distribution of (TiC) particles in the master alloy after extrusion process with uniform .shape will ensure a good quality. Synthesis of TiC, which contains of a liquid and solid interference reaction between Al melt and the carbon particles is evaluation from aggregated the TiC elevated temperature (superheated) before nucleation solidification[2]. Metal Matrix Composite (MMC) is one of the most attractive categories of material, and due to the important specification and applications of aluminum matrix composites among many types of composite, its became the first choice for high duty parts in terms of durability, and working in high elevated temperatures[3].

The main characteristic and specifications of TiC are come from the high interference and bonding between reinforcement phases and the matrix.[4]. Comparison between the particulates of composite (SiC) and (TiC) indicating that, the dissolution of TiC in the matrix of pure Al is much less than (SiC), therefore the TiC looks to be stable in the matrix [5]. During hot extrusion, particles recrystallization and rearrangement will take place; therefore the extent of this particle in the matrix will be homogeneous, but in cold extrusion, and due to sudden impact, the particles will be broken down in to small size, which result in finer allocation and distribution in the matrix body [6]. Comparison between hot and cold extrusion of aluminum matrix composite in base of impact strength values, show that there is a high reduction of this property in cold extrusion due to drastic plastic strain and residual stresses after extrusion. In hot extrusion of composite, the impact strength is better due to recrystallization and absent of these stresses [7].The uniform and well distribution of reinforced particles (TiC) in the as cast billet with a small size will carry over the extruded parts, and ensure the imprudent of stiffness and strength compared with un-reinforced [8]. Some times; grain-refiners can add to the matrix melt of (LM6) in specific amount. These refiners usually available in different size and different compositions. [9].

2. MOLD DESIGN and FINITE ELEMENT SIMULATION

The parts are produced by extrusion process using molding technique. So the first important step in this research is to layout the mold design according to the specific process. For this purpose; all the mold parts (punch, die, supports} have been design and drafted separately using AutoCAD software with all required dimensions and tolerances before fabrication process. "Fig. 1".shows the mold assembly.

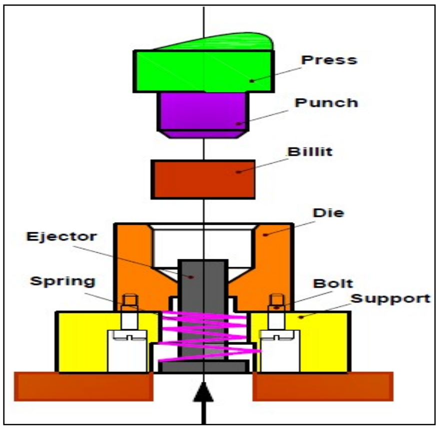


Fig.1. Extrusion mold assembly.

ABAQUS/CAE software are employed for implementing the finite element analysis and simulation for this process. It is high recommended for this simulation before the experiments to decrease and predict the errors before it's happened. In ABAQUS/ CAE; there are many steps should be follow strictly to find the accurate results. These steps include; creating the parts, define the materials, create instances in assembly, Mesh the parts, and define the interaction between the parts before submit the process for analysis. "Fig. 2".is a flow chart which illustrates these steps.

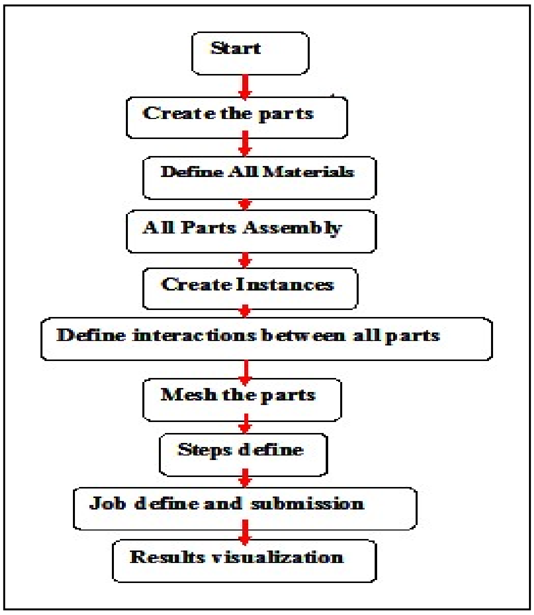


Fig. 2. ABAQUS simulation steps.

In this analysis; and because the mold parts are symmetric, so halve section of each geometry are represented as an axi-symmetrical deformable shell. The die and punch are represented as rigid body, but the billet is represented as deformable body. "Fig. 3" .represent the 2D and 3D model of these parts.

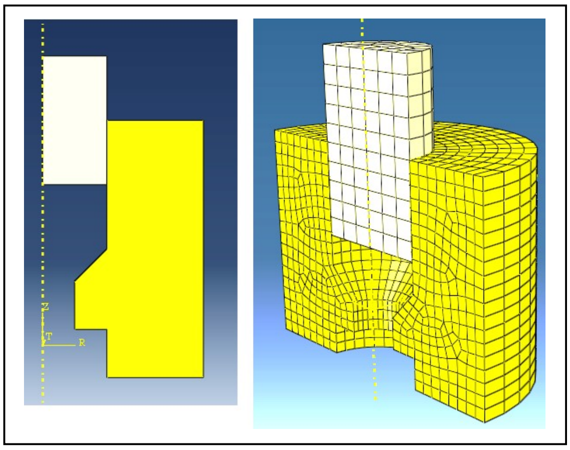


Fig. 3. 2D and 3D model of the Die and billet

During simulation process; definition of each material property will depend on the initial value of young modulus of elasticity (E). That's mean, the material with high (E) value will be rigid, and the others are deformable. Boundary condition of the system should be applied carefully. Its include constrain the die from all direction to prevent any displacements, and in same time to keep the billet free for motion after applying load from the upper surface , as shown in "Fig. 4

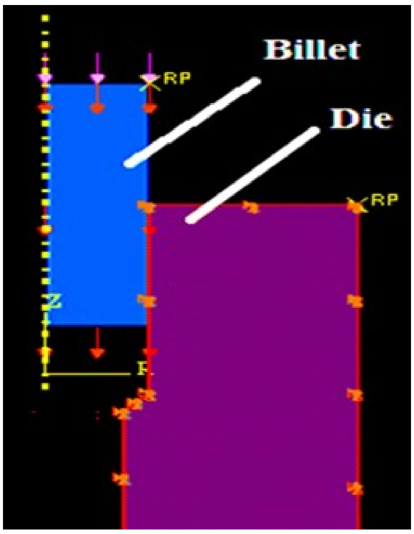


Fig. 4. Boundary condition.

In this simulation; the interaction between the parts is surface to surface contact, and denoted as master and slave. The die and punch will be master and the deformable billet is a slave. Simulation are repeated many time for each material (LM6) and the composite (LM6/TiC) to find the most effecting parameters which has the most effect on extrusion this composite material and diagnose the problems before the experiment. These parameters include extrusion speed, ejection method, and extrusion ratio. Stresses and heat concentration during the process in specific surfaces will give high indication about the material extrudability behaviour. "Fig. 5". Show the principal and the average values of generation stresses during simulation.

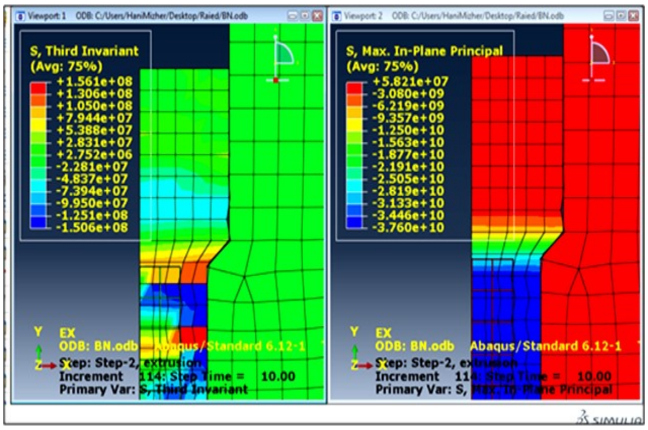
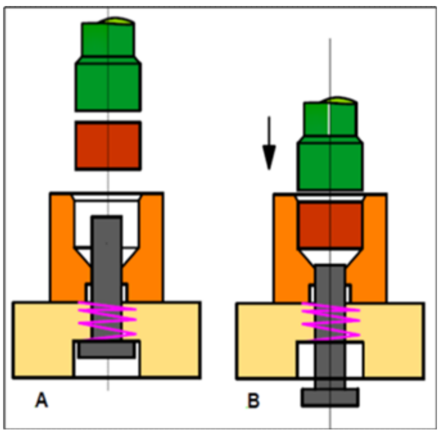


Fig. 5. Principal and average generation stresses.

3. MATERIAL PREPARATION and EXPERIMENTAL PROCESS

Four extrusion steps will be adopted to extrude the composite material with extrusion ratio (6:1), and extrusion speed (1 m/min). The first step includes alignment the die, billet, punch and press. In the second step, the press will push the billet inside the die. Extrusion the billet to the required demotions will be in third step, where the punch will push the billet inside the dia. Final product will be ejected in final step. "Fig. 6".and "Fig. 7".illustrate these four step.



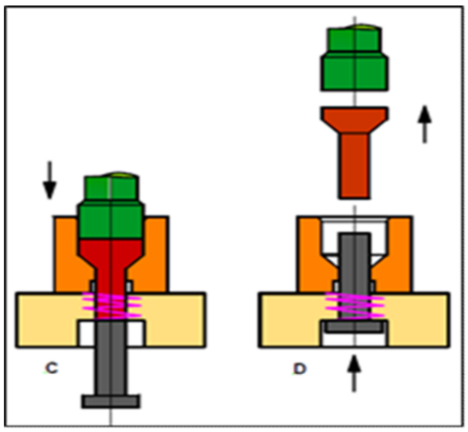


Fig. 6. First and second extrusion step.

Fig. 7. Third and Fourth extrusion step.

Preparing the billet material of aluminum metal matric composites (as cast) are previously available as shafts from the works done by other researcher as shown in "Fig. 8". Length and diameter are reducing by turning to the dimensions (60, 40) mm respectively. These billets will be extruded by direct hydraulic press to produce (10) mm diameter rod.

Fig. 8. Composite shafts before extrusion.

In this work, the matrix is aluminum silicon alloy (LM6), which consist of (11.8%) silicon, and the composite is titanium particulates (TiC) with (5) wt. % percentage. The chemical composition and mechanical properties of (LM6) are listed in "Table 1" and "Table 2".

Table 1. chemical composition of (LM6).

Element	**Composition of LM6 (%)**
Cu	0.1
Mg	0.1
Si	10- 13
Fe	0.6
Mn	0.5
Ni	0.1
Zn	0.1
Lead	0.1
Tin	0.05
Titanium	0.2
Other Elements	0.2
Al	Remainder

The main material of Titanium carbide (TiC) is hard ceramic, which has very good properties like wear resistance and high lubricating properties. The chemical composition and physical properties of (TiC) are listed in Table 3" and "Table 4".

Table 2. Mechanical properties of (LM6).

No.	Property	Values
1	0.2% Proof Stress (N/mm^2)	60-70
2	Tensile Stress (N/mm^2)	160-190
3	Elongation (%)	5-10
4	Impact Resistance. Izod (Nm)	6.0
5	Brinell Hardness Number	50-55
6	Endurance Limit (N/mm^2)	51
7	Modulus Of Elasticity (x 10^3 N/mm^2)	71
8	Shear Strength (N/mm^2)	120

Table 3: Chemical composition of TiC.

No.	Component	Wt%
1	Al	Al 0.005
2	Ca	0.005
3	Mo	0.1
4	C	19
5	Na+K	0.002
6	Mg	0.005
7	S	0.002
8	Ti	Remaining

Table 4: The Physical properties of TiC.

No.	Relative density	Molecular Weight	boiling point
1	4.93 g/mL at 25 °C	59, 88 g/mol’	4.820 °C

Mold parts were fabricated according to the basic design. Punch and die material should be tool steel, which can be hardened to (65) HRC in order to avoid and withstand shock and wearing. Also it’s fabricated as a portable inserts which can be replaced any time as in "Fig. 9".

Fig. 9. Different diameters of die inserts.

After fabricating all parts, the mold will be assemble according to the press specification. Fig. 10".show the completed mold assembly during the experiment.

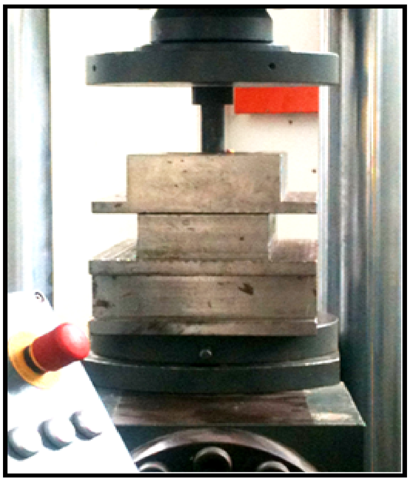


Fig. 10. Completed mould assembly on hydraulic press.

Experimental test is done in elevated temperature and many mechanical tests like; scanning electron microscope and hardness test was done to these samples to evaluate their properties after extrusion. Microstructures test by Scanning electron microscopy (SEM) require high quality surface, and the preparation should be according to the standard of microstructure test procedure. Samples before and after extrusion are sectioned and taken from different poisons like center, middle of cross section and outer surface respectively. Samples preparations process also includes polishing the surface to be very clean without any scratch, by using grinding, diamond suspensions, polishing by (0.1) μm diamond and etching by chemical solvents like hydrofluoric acid (HF), and (HNO3) as shown in "Fig. 11"

Fig. 11. Samples of composite ready for SEM test.

4. RESULTS and DISCUSSION

Simulation and experimental results are evaluated and comparison was done between these results. In Finite element analysis, the values of mises stresses are maximum in the area when the die diameter is narrow down. The particles dislocation which happened due to high friction and heat generation between the contact surfaces will maximize their values, as shown in "Fig. 12"

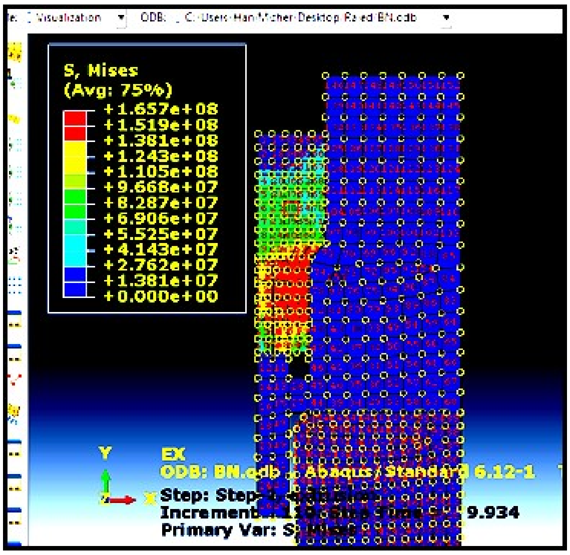


Fig. 12. Mises stresses.

The plastic strain is very high and distributed along the extrusion surfaces. Slip between the billet and die surfaces will generate high amount of interference and work hardening between the moving particles, as shown in "Fig. 13"

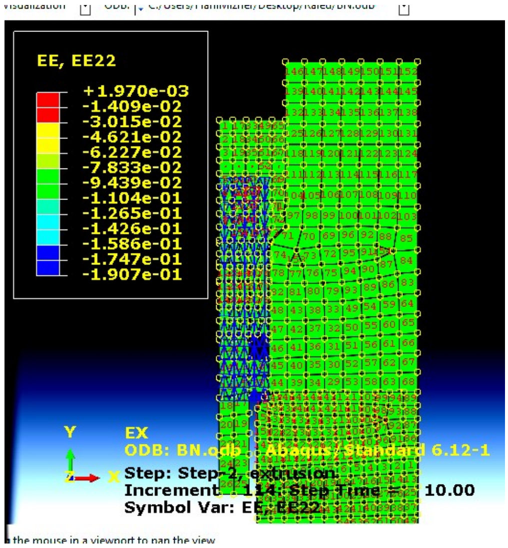


Fig. 13. Plastic strain.

Velocity contour show that, the speed of billet particles during extrusion will be at maximum values after the billet accede the narrow area in the die, and this speed will be in maximum values at the center of the billet, as shown in "Fig. 14".

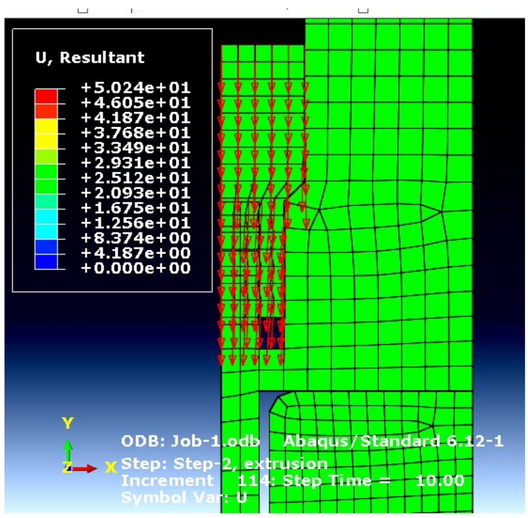
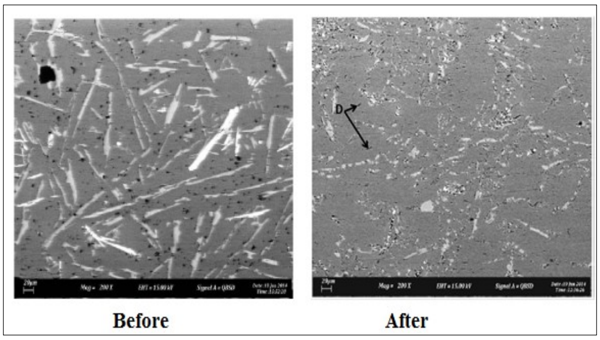


Fig. 14. Particles velocity.

Experimental results show that; the composite (LM6/TIC) can extrude properly, especially in elevated temperature comparing with (LM6) alloy. From many experiments, it’s found that, the extrudability of composite is depend on some parameters, which make it extrude as or near to (LM6); like suitable extrusion ratio, high surface finish of the die and extrusion speed. Microstructure test of many samples shows a good structure refinement after extrusion. Also (TiC) particulates possess a homogeneous distribution after the process. The homogeneous distribution of (TiC) particles in the master alloy after extrusion process with uniform shape will ensure a good quality. "Fig. 15".and "Fig. 16".show the micrographs of microstructure test for (LM6) alloy and the composite before and after extrusion process.



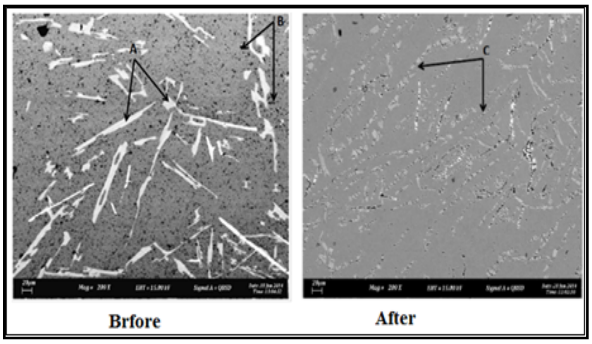


Fig. 15: Before extrusion. **Fig. 16:** After extrusion.

All composite specimens after extrusion process show high values of Young's modulus in addition to other mechanical properties. Mechanical tests like stiffness (E) and 0.2% proof strength are measured for many samples and repeated for several times in various loading until failure. "Fig. 17".Show the young modulus via volume fraction of (TiC).

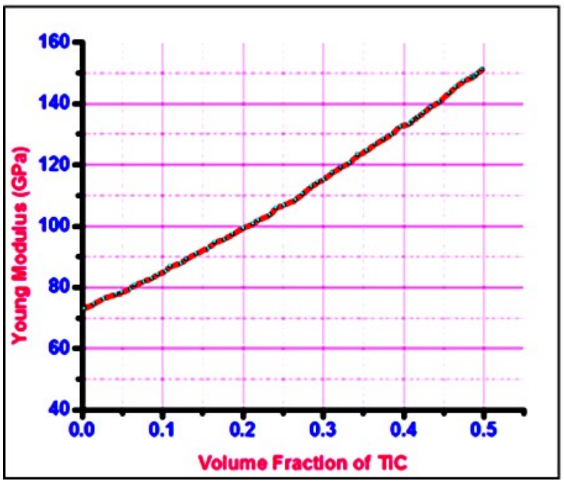


Fig. 17. Young modulus via volume fraction of (TiC).

Ultimate tensile strength (UTS) after extrusion also measured for LM6, Composite, and comparing with other aluminum alloy (L 168). It's found that the composite has a high value among the others, as shown in "Fig. 18".

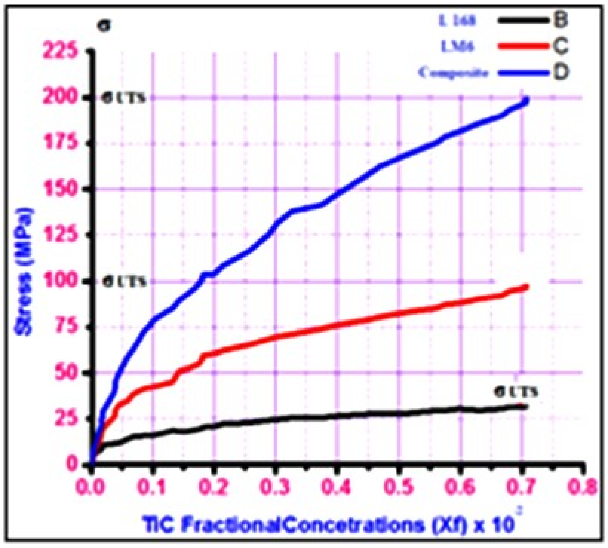


Fig. 18. (UTS) Comparison after extrusion for composite, LM6 and L168 alloy.

5. CONCLUSIONS

Theoretical and experimental results in this research are revealing for some conclusions. The main conclusions which built up are:-

1-Simulation results show that; the stress concentrations in the dead zone can be avoided during extrusion by controlling the extrusion angle and the effective distance.

2- Simulation results reveal that; this composite can show a good extrudability especially in elevated temperatures (520°C), which slightly above the temperature required to extrude the matrix alloy (LM6).

3-Extrudability of composite material (LM6/TiC) as well as depend on the initial billet (as cast) specifications, and whether this billet is homogenous or not.

4-Billets preparation before extrusion, like the centricity, temperature, and their dimensions according to the extrusion die are very important.

5- SEM micrographs of the extruded composite material show that, there is a high refinement in grain size after extrusion, and this will leads to improve and enhance many mechanical properties like hardness, wear resistance, as shown in "Fig. 19".

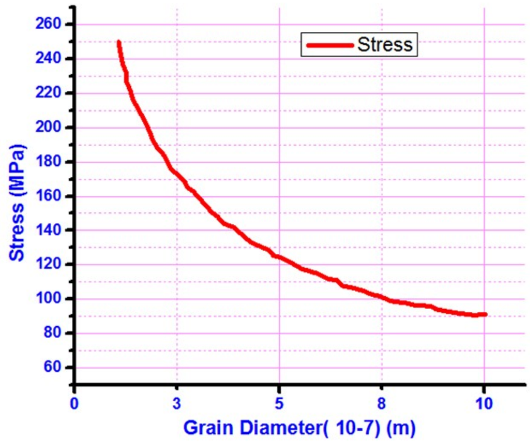


Fig. 19. Generations stresses via grain diameter.

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