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Analytical and Numerical Analysis of Extrusion Force, Stress and Strain Development During Extrusion Al6063-SiC Composite

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Abstract: Nowadays composite material are highly interesting in different areas like, aerospace, thermal management, automotive application, and electronic products etc. Aluminium based metal matrix with silicon carbide as particle reinforcements called discontinuous reinforced metal matrix composite materials. It has excellent mechanical properties like high yield strength, wear resistance, corrosion resistance and vibration resistance. During the development of discontinuous reinforcement metal matrix composites compression process like, extrusion is an advisable secondary process for homogenous distribution of the reinforcement's materials through the metal matrix. This research was investigated the metal flow behavior of extrusion load, stress and strain distribution of Al6063/Sic based discontinuous reinforcement metal matrix composite. The billets extruded from round billet to square shape and are used for different applications. Third order polynomial and cosine die profiles were used as extrusion dies for this research by taking 30%, 60% and 90% area reductions. Depends on these three different area reductions upper bound and DEFORM 3D finite element analysis method were used to analyze analytically and numerically respectively. Due to these different area reductions, the extrusion load was minimum in cosine die profiles both analytical and numerical results. In 30% of area reduction cosine die profile has optimum load (878.59N) and it used to extrude Al6063/20%SiC composite billet materials from 20mm input diameter to 14.8x14.8mm output square sides. Therefore, 30% area reduction cosine die profile has minimum extrusion load as compare other area reduction of cosine die and 3rd order polynomial dies. It is used as extrusion die for Al6063/SiC composite materials to optimum extrusion loads in different % of area reduction of square shape extruded.

Keywords: Metal Matrix Composite, Extrusion, Force, Strain and DEFORM-3D

1. Introduction

Nowadays composite material are highly interesting in different areas like, aerospace, thermal management, automotive application, and electric products etc. Metallic matrix composites are the combination of two or more different metals and form the metal matrix. They are produced by controlling the morphologies of the constitute s to achieve optimum combination properties. Properties of the composites depend on the properties of the constituent phases, their relative amount, and dispersed phase geometry including particle size, shape and orientation in the matrix. Aluminum metal matrix composite is one of metal matrix composite. Different types of reinforcement materials are used as to form aluminum metal matrix composite. These are some advantages in using particles reinforced AMCs materials than unreinforced materials such as- greater strength and high specific modulus, improved stiffness, light weight, low thermal expansion coefficient, high thermal conductivity, tailored electrical properties, increased wear resistance and improved damping capabilities. Reinforcing constituents can be incorporated within the matrix in the form of particles, short fibers, continuous fibers or mono filaments. Now it is used in aerospace, thermal management areas, industrial products, automotive applications such as engine piston, break disc etc. Md. Halibut et al [1].

There are two primary processes to develop AMC fabrication systems which are among at depend on temperature such as liquid phase processing techniques such as casting and solid phase processing techniques including powder metallurgy routes.

After the primary fabrication methods, there are also secondary processing techniques to develop AMC materials such as extrusion, rolling or forging are necessary for consolidating the composites and decreasing their porosity. Extrusion is a very effective step to improve the density and mechanical properties of MMCs. The extruded microstructures have a more uniform distribution of the SiC particles and the eutectic silicon by cooperation with as-cast microstructure. Evaluation of the mechanical properties show that the extrude samples have strength and ductility values superior to those of the as-cast counterparts. In the extruded samples the addition of increasing amount of particulate SiC increasing the yield and decreasing the ductility. The ductility level of the extruded samples is found to be higher than those of the forged as cast samples. The ductility level of the extruded samples is found to be higher than those of the forged as cast samples Jabbar Kasim Jabbar [2].

2. Literature Review

Conducting the literature review is done prior to undertaking the research. This is critically provided as much information as needed on the technologies available and methodologies used by other research counter parts around the world on the topics. This chapter provides the summery of the literature review on topics related to the extrusion of round to square shape die profiles.

Gouveia et al. [3] were studied the numerical and experimental analysis of the round to square extrusion of a model material by using combined Eulerian-Lagrangian formulation and updated Lagragian formation for analyzing a steady state metal forming process. The numerical results in both flow pattern and strain distribution have been shown to be in good agreement with the results obtained from the physical modeling experiments. In terms of numerical modeling, it can also be concluded that combined Eulerian-Lagrangian mesh models are more efficient for the analysis of steady-state metal forming processes, because the steady-state metal forming conditions are directly included in the finite element formulation. Finally, it should be noted that the combined Eulerian-Lagrangian formulation is computationally more efficient than the updated Lagrangian formulation for analyzing a steady-state metal forming process, as it requires much less CPU time.

Celik et al. [4] were studied based on the upper bound analysis, for the design of three dimensional off centric extrusion arbitrarily shaped dies were applied to the off centric extrusion square section from initially round billet with experimental verifications. A finite element analysis was written to obtain the optimum die design which yields the lowest upper bound for a given reduction in area, die length off-centric positioning and frictional conditions. There were both computations carried out for the converging (ruled surface) and smooth curved dies. The theoretical prediction were observed to The theoretical predictions were observed to be in agreement with the experiment results.

C. W. Wu et al. [5] were presented a model based on upper bound theorem to analyze the extrusion of composite clads rods with non-axisymmetric cross section. Velocity fields for both core and sleeve are generated with the assistance of a product cross sectional profile functions. Rectangular, hexagonal, and octagonal section products are chosen as the study objects. Numerical results are discussed for various process variables such as semi die angle, reduction of area, frictional condition of die, and product shape complexity.

Gouveia et al. [6] were studied the physical and numerical modeling, which are intended to serve as design aids of 3D forward extrusion process. A comparative examination between different techniques has been performed under the theoretical and experimental analysis of round to square forward extrusion process. Experimental results confirm the physical modeling is capable of providing relative quantitative information on the behavior of a complex 3D extrusion process, especially the strain distribution. Updated Lagrangian finite element numerical simulation show a good agreement with the result of the physical modeling experiment in terms of replicating the flow pattern and the distribution of strain

R. K. Sahoo et al [7] were found an upper bound solution for the extrusion of channel section from round billet though the taper die. The rigid perfectly plastic model of the material is assumed, and the spatial elementary rigid region technique is presented for which the kinematically admissible velocity field is found out by minimizing the plastic dissipation of power. The presented analysis allows for specification of process control parameters and their relation to extrusion load, equivalent die angle, reduction ratios and friction factor.

Joseph S et al. [8] were studied upper bound elemental for prediction of extrusion pressure in 3D forward extrusion process is presented. Using square or rectangular billets, the study of the effect of die land length has been extended for the evaluation of extrusion pressures to extrude sections such as circular, square and rectangular shape sections with power of deformation due to ironing effect at the die land taken into account. The effect of die land length on the extrusion pressures increases with increasing complexity of die openings geometry with rectangular section giving the highest extrusion pressure followed by circular with square section die opening, giving the least extrusion pressure for any given die reduction at any given die land lengths. The proper choice of die land length is imperative if excessive pressure buildup at the emergent section is to be avoided so as to maintain good quality and metallurgical structure of the extrudes.

K. Abrinia et al. [9] were designed for profiled sections such as square, rectangular, and elliptical cross shapes. These dies force the material to flow sideways and spread so as to extrude sections with wider dimensions than the initial billet or the maximum container diameter. The geometry of the deformation zone in the die was formulated and based upon that, a kinematically admissible velocity field was derived. Using this velocity, estimated the field upper bound on extrusion power. Different die profiles were investigated and the influence of area reduction and die length on the extrusion pressure was studied. Finite element analysis for the numerical simulation of the process and design process of the extrusion dies was also carried out. Comparison of the results showed good agreement between the theoretical, numerical and experimental data.

Kumar Rout et al. [10] were investigated a numerical analysis of extrusion through cosine die profile using DEFORM software for plane strain deformation using rigid plastic material. The extrusion load, stress, strain, strain rate and velocity distribution have been determined. It is proposed to investigate the evaluation of uniform microstructure and the effect of strain hardening in the extrusion process in future work.

A. K. Rout et al. [11] were investigated a numerical Finite element modeling has been carried out for extrusion of triangular section from round billet through a curved die using DEFORM -3D software for steady state deformation using rigid plastic material. The extrusion load, stress, strain, strain rate, temperature and velocity distribution have been determined. Comparison of the results showed good agreement between the theoretical, numerical and experimental data.

F. GhaemI eT al.[12] were studied an optimum extrusion die profile through implementation of slap analysis in a computational algorithm. Moreover, extrusion process through both optimum conical and curved die has been performed experimentally and finite element method. It has been demonstrate that material work hardening characteristics and friction condition have remarkable effects on the optimum streamlined die profile. The results prove that streamlined die profile designed based on the developed approach, is superior to the conventional conical dies from both metallurgical and manufacturing perspectives. Consequently, the proposed method can be regarded as an efficient and reliable tool for designing streamlined die profiles. Therefore, this technique can be used to produce desirable conditions in both process and product quality in terms of extrusion force, deformation homogeneity and die wear.

Aue-u-lan Y. et al. [13] were studied effect of extrusion speed on the extrusion load, temperature distribution and the stress concentration in the pothole die. The aluminium square hollow profile size 1.7x1.7 inch with the wall thickness of mm was used in this study. The aluminium initial billet was made of Al6063-T5 which has the diameter of 127mm and length of 508mm and the extrusion ratio was 106. Finite element modeling was employed and the simulation results demonstrated that the extrusion load and temperature over the whole extrusion process was not uniform, and the die uniform and the stress analysis could predict the weak area in the porthole die.

Debabrata Rath et al. [14] were studied the changes of die angle, area reduction in dies, loading rate on the final extruded product, extrusion pressure of lead of circular cross sections has been investigated experimentally. The proposed method is successfully adapted to the forward extrusion of the equilateral triangular section from round billet through converging dies of different area reductions. Computation of extrusion pressure at various areas was found that extrusion pressure increase with increase in reduction and calculations of different parameters (stress, strain etc.) in wet condition.

Maity et al. [15] were investigate a die profile is designed for extrusion of square section from round billet with a cosine die profile. It is proposed to carry out FEM modeling using DEFORM 3D software for lead and aluminum.

Singh pachalasiya [16] was studied anon-liner converging cosine dies profile are used for square to square extrusion process. CATIA, solid work, MATLAB, and DEFORM 3D software are used to design the cosine die profile. Extrusion was isothermal condition, for extrusion purpose Al6062 and Tellurium Led to compare the results of strain, strain rate, stress, velocity, load, pressure and temperature of the extrusion process.

Venkatesan et al. [17] were investigate the metal flow behavior of Al-B4C based DRMM composite extruded from round to hexagonal through six different die profiles namely third order polynomial, cosine, elliptical, hyperbolic and conical geometry. Extrusion load, stress, strain distribution, and metal flow for above said die profiles are predicted by using analytical approach upper bound technique and compared with finite element method. Cosine and third order polynomial profiles are found to be most optimal in terms of homogenous and minimal extrusion load requirement.

Venkatesh et al. [18] were investigate the metal flow behavior of Al-SiC of Al– based DRMM composite extruded from round to hexagonal through six different die profiles namely third order polynomial, cosine, elliptical, hyperbolic and conical geometry Extrusion load, stress, strain distribution, and metal flow for above said die profiles are predicted by using analytical approach upper bound technique and compared with finite element method. Cosine and third order polynomial profiles are found to be most optimal in terms of homogenous and minimal extrusion load requirement.

Pathak et al. [19 were studied, die angle of the square rod extrusion process was optimized to produced micro structurally round product at maximum production speed and minimum left out material in the die. The design problem is formulated as a nonlinear programming problem which is solved using genetic algorithm. Selection of the processing parameters is carried out using dynamic material modeling (DMM). Using this approach a square rod extrusion problem is successfully designed.

S. T. Oyinbo et al. [20] were investigate using linearly converging die profiles, the extrusion of simple and advanced polygons such as circular, square, triangular, hexagonal, heptagonal, octagonal, L-, T-, and H-sections from round billet have been numerically simulated. Autodesk invertor 2013 and DEFORM 3D software are used for extrusion of the above section from round billet was then performed, for dry and lubrication condition, the load, stress, strain, velocity, temperature distribution during the deformation. It is found that the predictive loads for advance (asymmetric) shapes are found to be higher than that of the simple shapes. While there is no marked difference between the prediction load for simple (axisymmetric) shapes, the L-section has the highest extrusion load, followed by T-section and the H-section given the least pressure.

A. García-Domínguez, et al. [21] were presented a comparative study of extrusion processes (solid and cup extrusion), considering both direct and in direct forming conditions and showing the most interesting difference between them. The comparison is realized by finite element method using DEFORM F2 and the material is low carbon steel (AISI-1010). The result was concluding that the required loads are higher in cup extrusion process due to the higher friction forces.

Peyman Karam et al. [22] were provided a new formulation for the analysis of the extrusion process for non- axisymmetric sections. The upper bound theorem has been used to obtain a generalized kinematically admissible velocity field and considering variation of the dead zone size at different angular positions and 3D curved surfaces. Using this analytical method, extrusion of square, rectangular and L-shape sections were analyzed and the effect of shape complexity on material flow and dead material zone (DMZ) formation under different conditions has been investigated. Physical modeling experiments and finite element analysis were carried out to reveal the capability of the proposed theoretical method.

H. H. Kim et al. [23] were studied multiwall CNT/Al_2O_3 performed based aluminum hybrid composites were fabricated using the infiltration method. Then, the composites were extruding to evaluate the mechanical properties. The required extrusion pressure of hybrid MMCs increased as the Al2O3/ CNT fraction increased. The deformation resistance of hybrid material was over two times that of the original Al356 aluminum alloy material due to strengthening by the Al2O3/ CNTs reinforcements. Increasing temperature of the material can help increase formability. In particular, temperatures under 623 K (3500C) and over-incorporating reinforcements (Al_2O_3 20 pct, CNTs 3 pct) are not recommended owing to a significant increase in the brittleness of the hybrid material.

Beata Pawłowska [24] were presented the analysis of nature of metal flow during extrusion of non-circular section and determining the relationship between extrusion force and geometrical parameters of extrude (the shape extrude). Experimental procedure was carried out for the simplest cases of non-circular profiles (triangle, square, rectangular) of various geometrical parameters. Determining parameters of metals plastic flow (the depth of plastic zone Lp and the dead zone angle αsm) it has been shown the difference in nature of metal flow during extrusion product differing in non-circular sections. This differentiation results in the complex nature of flow consequential from change with circular section of the billet to non-circular section of extrude. It has been shown that flow resistance can be different with regard to appearing configurations of deformation zones (the size and shape of plastic zone, dead and shear zones) and dependent from for example geometrical parameters of a die.

Kumar Mohapatra et al.[25] were investigate simulation of extrusion of square section from a square billet (AA-6XXX) through converging die has carried out using DEFORM 3D commercial package and the effect of few state variables on the process has been studied. The simulation was performed by both linear converging and cosine die profile, to ascertain extrusion load, effective stress, effective strain and temperature distribution. To decipher the effect of die length, ram velocity and extrusion ratio on the process, simulations were carried out by varying the variables in a wide range for both type of dies. The optimum die length for cosine die is a bit larger than linear converging die for a particular reduction. The investigation reveals that extrusion through cosine die is more favorable than shear faced die and linear converging die profile due to lesser velocity and load exists.

S. K. Mohapatra et al. [26] were investigate the effect of various process parameters for determining extrusion load has been studied for square to square extrusion of Al-6061 alloy, a most used aluminium alloy series in forming industries. Parameters like operating temperature, friction condition, ram velocity, extrusion ratio and die length have been chosen as an input variable for this study. Operating temperature, extrusion ratio, friction factor, ram velocity and die length have the significant effect in decreasing order on the maximum load requirement.

Marcelo et al. [27] were investigate and validated the novel numerical scheme to calculate the velocity, stress, strain, pressure and strain rate fields of metal plastic flow in direct extrusion processes by employing the finite volume method, FVM by using the Explicit MacCormack Method in structured, fixed and collocated mesh. Simple method was applied to attain the necessary pressure-velocity coupling. These new numerical scheme was applied to the analysis of direct hot extrusion process of Al 6351 and Al 6060 aluminium alloys. The velocity and other variables fields achieved fast convergence and a good agreement with experimental results from Visio plasticity tests by the grid stripe pattern technique and Forge 2008 software.

Research Gaps- Researchers have done round billet to square shape die profiles by using different mathematical techniques with different extruded materials to improve the materials property and minimize the extrusion force. There is a research gap in Al/SiC composite material extrusions from round to square die shape. No one done the extrusion of Al/SiC composite materials from round to square shape die profiles by comparing cosine dies and 3rd order polynomial dies. The reason of comparing two dies is used to extrude Al/SiC composite materials in optimal extrusion load. In the present work, consider two die profiles (like; 3rd order polynomial and cosine dies) in three dimensional extrusions through non-linear converging die for extrusions of Al6063/20%SiC composite materials from round billet to square die profile by using both upper bound method and finite element modeling.

3. Materials and Method

3.1. Materials

Depend on; Availability, Machinability, Cost, High strength and High corrosion resistance Aluminium6xxx – (Al-Mg-Si) Alloys are used to work this thesis.

Aluminium6xxx – (Al-Mg-Si) Alloys

1. Heat treatable

2. High corrosion resistance, excellent extrudability moderate strength
3. Building & construction, highway, automotive, marine application
4. Representative alloys: 6061, 6063, 6111

The 6xxx alloys are heat treatable, and have moderately high strength coupled with excellent corrosion resistance. They are readily welded. A unique feature is their extrudability, making them the first choice for architectural and structural members where unusual or particularly strength- or stiffness-criticality is important.

Alloy 6063 is perhaps the most widely used because of its extrudability; and is used for the automotive space frame parts. Due to this property and the availability of Al6063 is used as the working material. (The Aluminum Association, Inc., www.aluminum.org)

Silicon carbides are used for particulate reinforcement materials in the aluminium metal matrix composite.

3.2. Methods

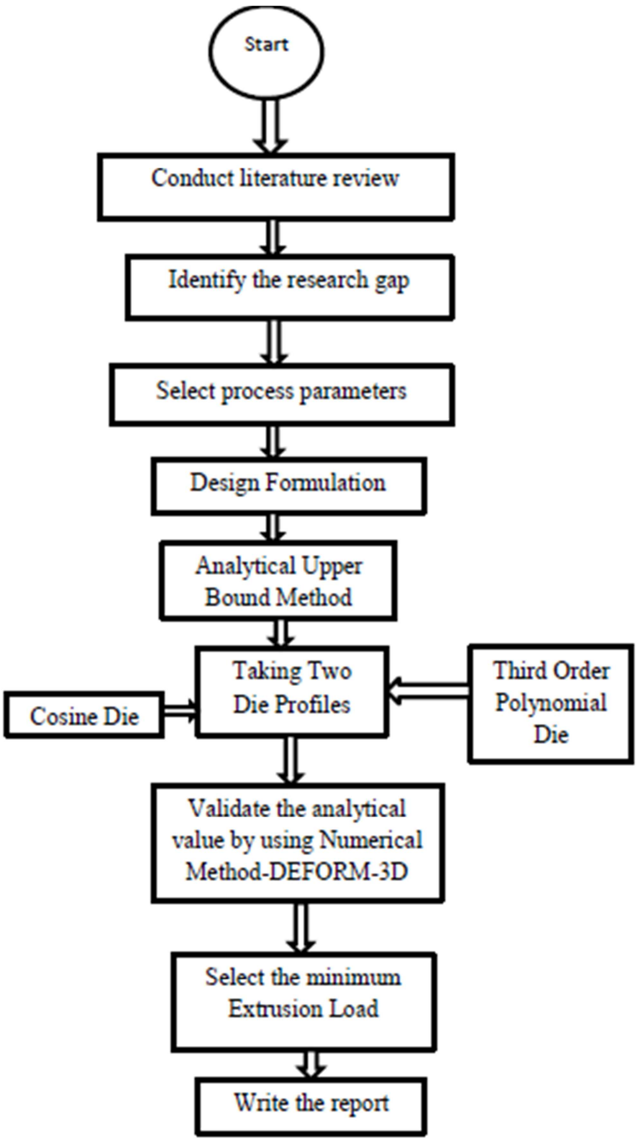


Figure 1. *Flow chart of over methodology.*

4. Theoretical and Mathematical Analysis

4.1. Upper Bound Methods for Three-Dimensional Metal Deformation Problems

For problems relating to many metal working operations, exact solution for the load to cause unconstrained plastic deformation is either non-existent or is too difficult to compute. In such cases, approximate analysis is available to establish the deformation load. Two such approximate methods have found extensive application in the analysis of quasi-static metal forming process, i.e., the upper bound and the lower bound techniques.

The upper-bound theorem predicts the power necessary to perform the desired metal forming at the prescribed velocities. However, since the velocity field for a given problem is generally not known, the power for any velocity field as calculated by the upper-bound theorem is greater than or equal to the actual power.

The development also applies to any velocity field which satisfies the boundary and plasticity requirements. Thus for any possible velocity field there also exists an associated total power. The actual velocity field is that which minimizes the associated total power and the actual total power is the minimum associated total power. The formal statement of the upper-bound theorem is that amongst all kinematically admissible velocity fields, the actual field minimizes the work-function *J*, where, J is the total power consumptions required to deform the circular billet into square section through the two different die profile and is denoted as the sum of the power losses due to the plastic deformation inside the die (WI), due to the velocity discontinuities at the entry (We) and at the exit (Wf) and due to the frictional resistance at the interface between die and material (Ws). So, C. Venkatesh et al. [18]

$$J=WI+We+Wf+Ws \qquad (1)$$

But streamlined die profile is concerned, that the velocity components at the entry and exit are uniform, then the equation becomes as

$$J=WI+Ws \qquad (2)$$

Power loss due to internal deformation

$$WI=\left(\frac{2\sigma_0}{\sqrt{3}}\right)\int_v \sqrt{(\varepsilon_{ij}\varepsilon_{ij})}\, dv \qquad (3)$$

$$WI=\frac{2\sigma_y}{\sqrt{3}}\int_0^z\int_0^r\int_0^\theta \sqrt{\frac{\varepsilon_{rr}^2+\varepsilon_{\theta\theta}^2+\varepsilon_{zz}^2+\varepsilon_{r\theta}^2+\varepsilon_{\theta z}^2\varepsilon_{rz}^2}{2}}\, d\theta drdz$$

Power loss due to frictional resistance:

$$Ws=\frac{m\sigma_y}{\sqrt{3}}\int_0^z\int_0^\theta \sqrt{v_r^2+v_\theta^2+v_z^2}\sec\alpha\, d\theta dz \qquad (4)$$

The angle α is the angle of inclination of the element of the die surface for all two die profiles with respect to the projected surface of the element on the rz plane. Knowing the velocity components, strain rate components of the individual die profile of the two different profiles, the volume integral was carried out using Simpson's one-third techniques. The average extrusion load (Pave) and effective stress can be determined from the total power consumption as follows,

$$P_{ave}=\frac{1}{\pi V0 R_1^2} \quad (5)$$

4.2. Equation of Velocity and Strain Rate Fields

During an execution of upper bound technique to analysis plastic deformation, an efficiently formulated velocity field is required to ensure the accuracy of the final solution. The velocity components must satisfy the incompressibility condition in order to be kinematically admissible. The billet material is assumed to be rigid at the outside, the entry and the exit of the die section, hence the velocity profile at this section is assumed to be uniform. An assumption is extended that the flow pattern of the material in the deformation zone can be represented in the same functional from as the die profile. In the present work, the geometric shape of the die profile is considered to be a key variant for optimal effect. Hence, two different die profile geometries have been N. Venkata Reddy et al [28] is given by:

$$r=\xi R\,(z) \quad (6)$$

Where constant ξ represents a stream-line with value ranging from zero at the axis to unity at the die surface and R (z) represents the cosine and 3rd order polynomial die profiles in eqn. 7 and 8 respectively.

$$X=Y=R\,(z)=\frac{R_1+R_2}{2}+\frac{R_1-R_2}{2}\cos(\frac{\pi z}{L}) \quad (7)$$

$$R\,(z)=R1+(R1-R2)[2\frac{Z^3}{L^3}-3\frac{Z^2}{L^2}] \quad (8)$$

Since the stream function has to satisfy the condition of uniform axial velocity V_0 at the entry section (radius R1) and the symmetry condition at ξ=0, it can be assumed as:

$$\psi=\frac{V_0 R_1^2 \xi^2}{2} \quad (9)$$

The velocity components Vr, Vθ and Vz are analytically derived in terms of the die profile from the derivatives of the stream function for the six different profile functions as: C. Venkatesh et al. [18]

$$Vz=\frac{\partial\psi}{r d_r}=\frac{V_0 R_1^2}{R^2(z)} \quad (10)$$

$$Vr=\frac{\partial\psi}{r d_r}=\frac{\xi V_0 R_1^2 R'}{R^2(z)} \quad (11)$$

$$V_\theta=\frac{V_r}{r}=\frac{V_0 R_1^2 R'(z)}{R^3(z)} \quad (12)$$

From the velocity field eqn. 10, 11and 12 the strain rate components can be derived as follows:

$$\varepsilon_{rr}=\frac{\partial V_r}{\partial r}=\frac{V_0 R_1^2 R'(z)}{R^3(z)} \quad (13)$$

$$\varepsilon_{zz}=\frac{\partial V_z}{\partial z}=-\frac{V_0 R_1^2 R'(z)}{R^3(z)} \quad (14)$$

$$\varepsilon_{\theta\theta}=\frac{1}{r}[\frac{\partial V_\theta}{\partial\theta}+Vr]=2\frac{V_0 R_1^2 R'(z)}{R^3(z)} \quad (15)$$

$$\varepsilon_{r\theta}=\frac{\partial V_\theta}{2\partial\theta}-\frac{V_\theta}{r}+\frac{\partial V_r}{r\partial\theta}=-\frac{V_0 R_1^2 R'(z)}{2R^3(z)}-3\xi \quad (16)$$

$$\varepsilon_{z\theta}=\frac{\partial V_\theta}{2\partial z}+\frac{\partial V_\theta}{r\partial\theta}=-\frac{3V_0 R_1^2 R''(z)}{2R^4(z)} \quad (17)$$

$$\varepsilon_{zr}=\frac{\partial V_r}{2\partial z}+\frac{\partial V_z}{\partial r}=-\frac{V_0 R_1^2 R'(z)}{R^3(z)}[1+\frac{1}{\xi}] \quad (18)$$

Where $R'(z)=\frac{dR(z)}{d_z}$ and $R''(z)=\frac{d^2R(z)}{dz^2}$

Strian,

$$\varepsilon=\int\frac{\varepsilon'}{Vz}dz=\int\sqrt{\frac{\frac{2}{\sqrt{3}}\frac{\varepsilon_{rr}^2+\varepsilon_{\theta\theta}^2+\varepsilon_{zz}^2+\varepsilon_{r\theta}^2+\varepsilon_{rz}^2+\varepsilon_{\theta z}^2}{2}}{Vz}}dz \quad (19)$$

Where

ε-strain

ε'-strain rate effective

Vz-velocity in the axial component

Using the above equation to calculate the two die profiles (3rd op and cosine) consumption power, extrusion load, strain and die geometry at three different percentage of area reduction (i.e. 30%, 60% and 90%).

4.3. Die Geometry

Extrusion is important to all plastic processing. The required die profile to achieve the desired product dimentions is a very complex task and requires detailed knowledge of material properties and flow, heat transfer phenomena. Extrusion die design is still more an art than a science, even though the latter is becoming more and more relevant for design optimization because of modern advancement in the powerful computation and modeling of complex flow and heat transfer processes, before, through and after the die. The proper design of an extrusion die is extremely important to achieve the desired shape and accurate dimensions of the extruded product. So, could be calculated an extrusion die profile for square section from round billet using cosine function and 3rd order polynomial function. The die profile functions are C. venkatesh et al. [18] written in eqn. 7 and 8 above. The die profile function R (z) is similar in both x and y direction. The die profile function satisfies the boundary condition such as that at z=0, x=R1 and z=L, x=R2. The exit and entry angles are non-zero angles. The velocity discontinuity surfaces are normal to the axial flow directions. Where R1 and R2 are semi width of billet and product respectively and L is the die length.

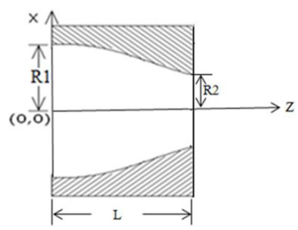


Figure 2. *Axisymmetric dies profile shape.*

4.3.1. Die Profiles

In this section die design for 30%, 60% and 90% reduction considered for cosine die profile and 3rd order polynomial dies profile equation different for different % of reduction shown below.

1. Cosine Die profile

Table 1. Dimensions of dies are at different % of area reductions.

s/n	% of Ared	Rip (mm)	Aip (mm^2)	Lop (mm)	Aop	H (mm)
1	30	10	314.14	14.8	219.04	10
2	60	10	314.14	11.2	125.44	10
3	90	10	314.14	5.6	31.36	10

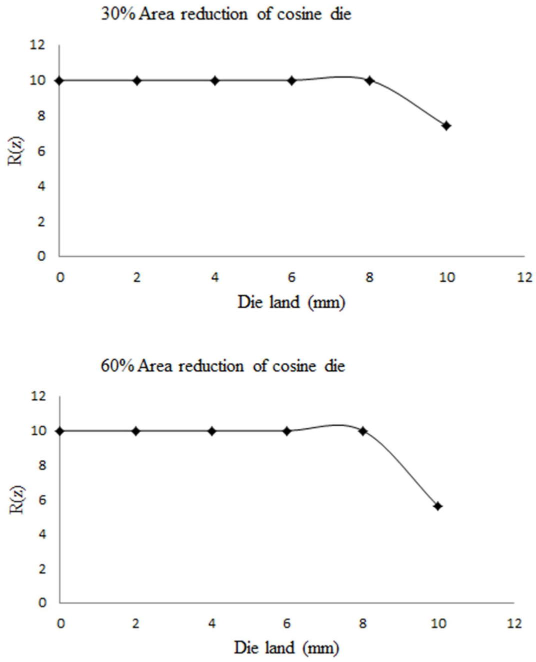


Figure 3. *Cosine dies profile 30% & 60% area reduction.*

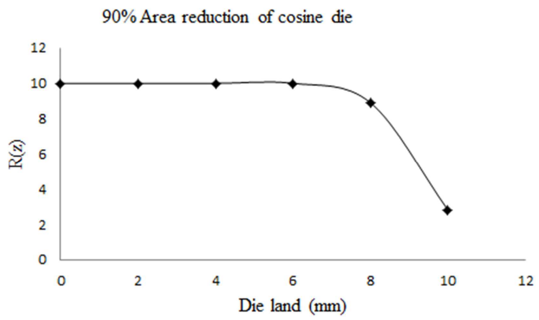
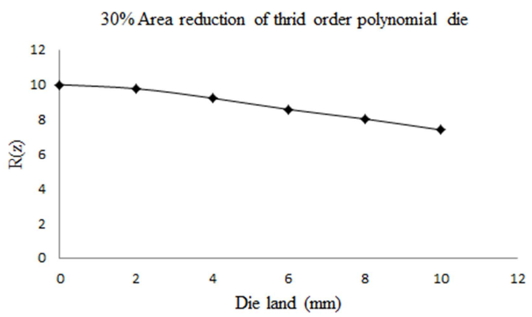


Figure 4. *Cosine dies profile 90% area reduction.*

2. Third-order polynomial dies profile



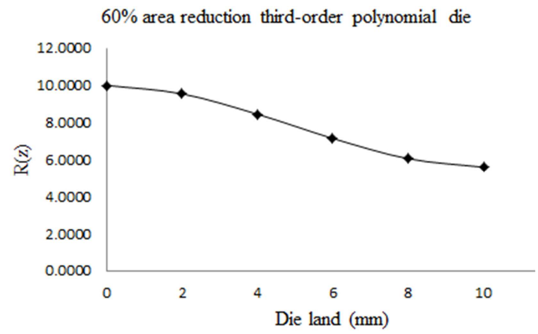


Figure 5. *Third-order polynomial dies profile 30% & 60% Area reduction.*

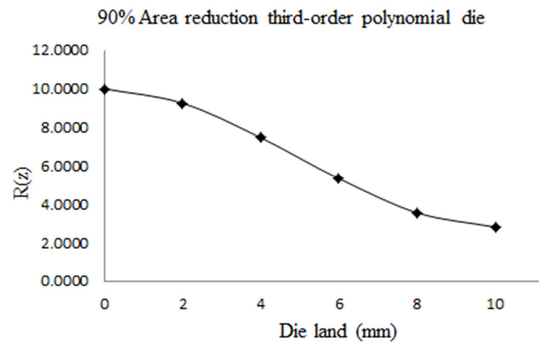


Figure 6. *Third order polynomial dies profile 90% Area reduction.*

4.3.2. Solid Modeling

For solid work drawing and simulation have taken die dimensions in the following table based on some previous experimental research results.

Table 2. *Parts of die dimensions for solid work drawing and simulations.*

s/n	Part Name	Dimension (mm)		Materials
		Cross section	length	
1	Punch	20 dia.	130	H13
2	Container	100 dia.	110	H13
3	Billet	20 dia.	110	Al/SiC
4	Die	30 dia.	20	H13
5	Die holder	100	20	H13
6	Base plate	120	20	H13
7	Bolt	M8	60	Harden steel

4.4. Numerical Analysis Method

In numerical analysis FEM modeling is a powerful technique used for different metal deformation problems including extrusion. In the present study, FEM modeling has been carried out for extrusion of square section from circular billet with cosine and 3rd order polynomial die profile using DEFORM-3D software. Effective strain rate (mm/mm/sec), effective stress (MPa), load prediction and temperature (°C) distribution during simulation process.

A FEM based program DEFORM 3D software which consists of three special features such as,

1. Pre processor
2. FEM simulation
3. Post processor

1. Pre processor

Input parameters;

1. Using Norton –Hoff Law $\sigma=K(\varepsilon_0+\varepsilon)^n\dot{\varepsilon}^m$ exp on the software and could be filled the values of K and n.
2. Working Temperature=450°C
3. Speed=2mm/sec
4. Friction=0.3

2. Extrusion Simulation and Post-processing

In post processing the result, after the simulation has completed DEFORM 3D post under post processor. In post processing the result obtained by step selection, state variables (like, strain rate effective, stress effective, load and temperature etc.). In point tracking to open the point tracking window by click the icon, and see the graph with point tracking. In slicing objects by clicking the icon to open the slicing window then the object can be sliced in several different ways. When finished the process exit the post processor by clicking the exit icon and back in to the main window, exit DEFORM 3D by clicking exit icon.

Extrusion simulation and post-processing in Cosine Die at different area reductions

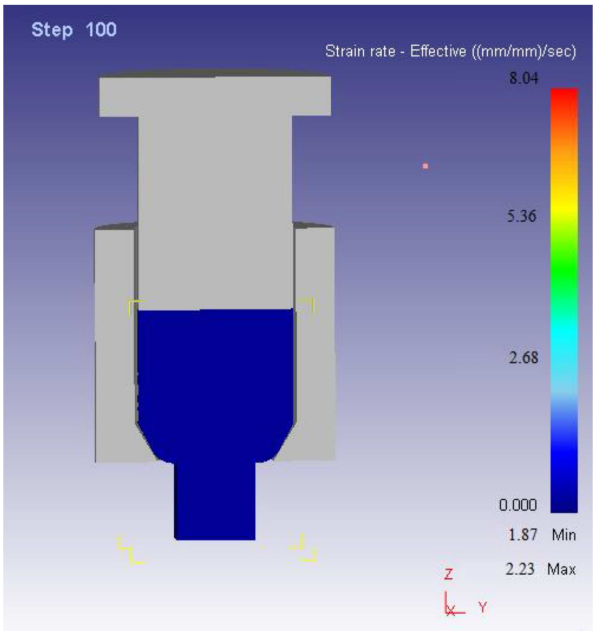


Figure 7. *Cosine dies Strain rate effective (30%).*

Figure 7 has shown the maximum and the minimum strain rate in 30% area reduction of cosine dies. The values are 2.23 and 1.87 ((mm/mm)/sec) respectively. Figure 8 has shown uniform temperature distribution throughout the system, but some temperatures were loosed due to the instruction between top die and billet materials.

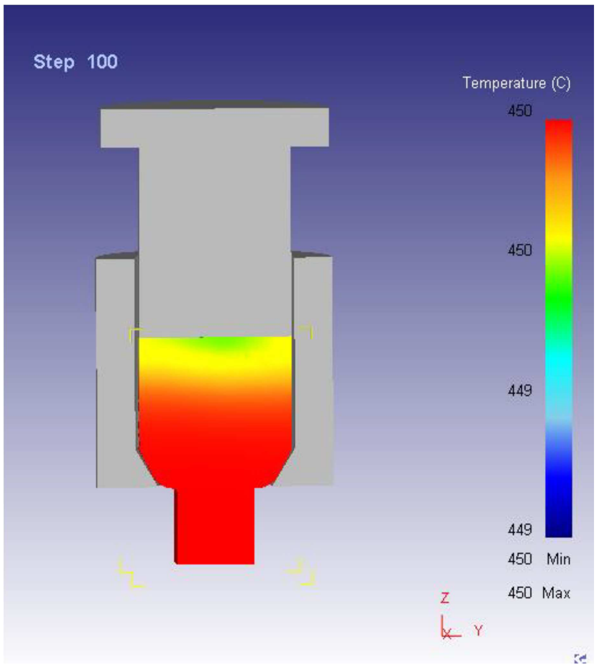


Figure 8. *Cosine dies Strain rate effective (30%).*

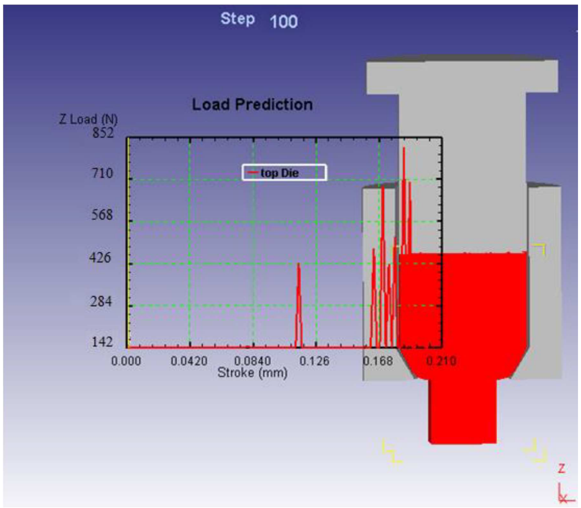


Figure 9. *Cosine dies Load prediction (30%).*

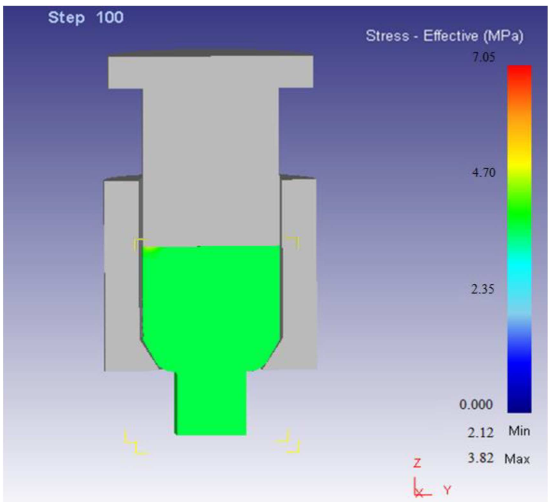


Figure 10. *Cosine dies Load prediction (30%).*

In Figure 9 has shown above the load prediction of the extrusion and the values of the extrusion load displayed on the graph was 820N. Figure 10 shows the maximum and minimum stress effectives on the extrusion process and the values were given 3.82 and 2.12 MPa respectively. The green color shows the maximum stress effective and the blue color shows the minimum stress effective.

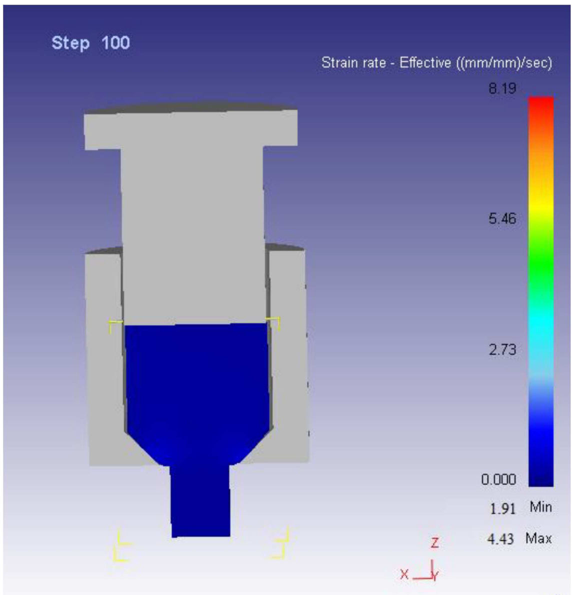


Figure 11. *Strain rate effective for 60% reduction cosine die profile.*

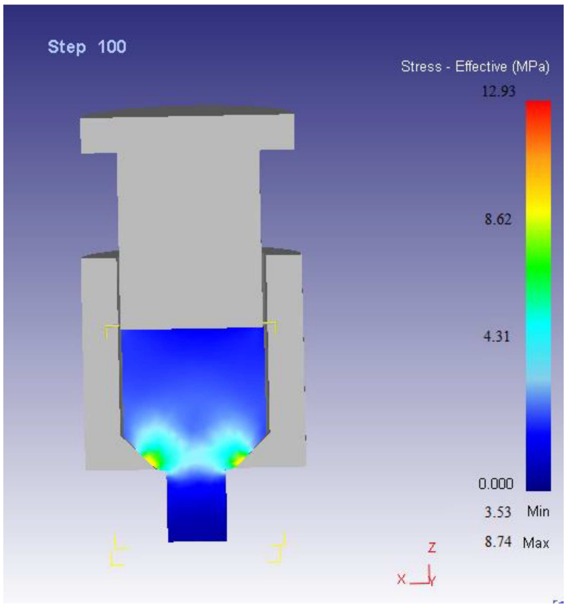


Figure 12. *Stress effective for 60% reduction cosine dies profile.*

Figure 11 has shown the maximum and the minimum strain rate in 60% area reduction of cosine dies. The values are 4.43 and 1.91 ((mm/mm)/sec) respectively. Figure 12 shown the maximum and minimum stress effectives on the extrusion process 60% area reduction of cosine dies and the values are given 8.74 and 3.53 MPa respectively. The yellow color shows the maximum stress effective and the blue color shows the minimum stress effective.

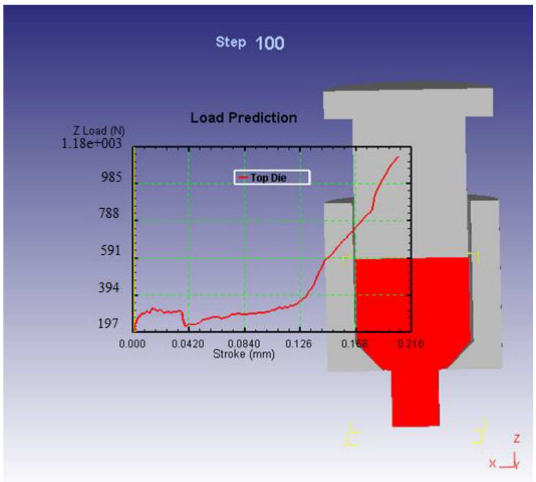


Figure 13. *Cosine dies Load prediction (60%).*

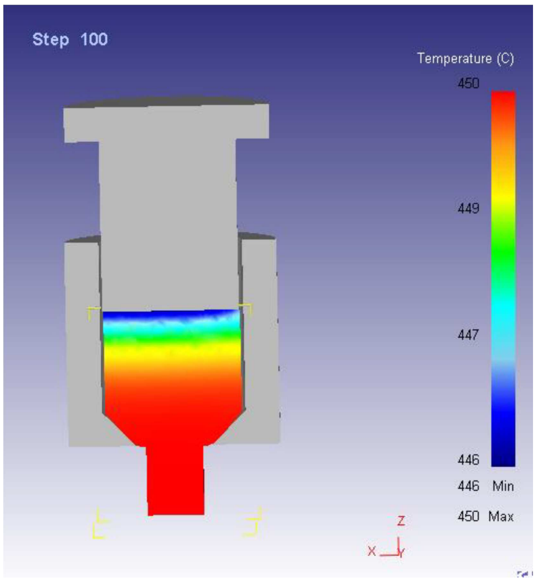


Figure 14. *Cosine dies Temperature (60%).*

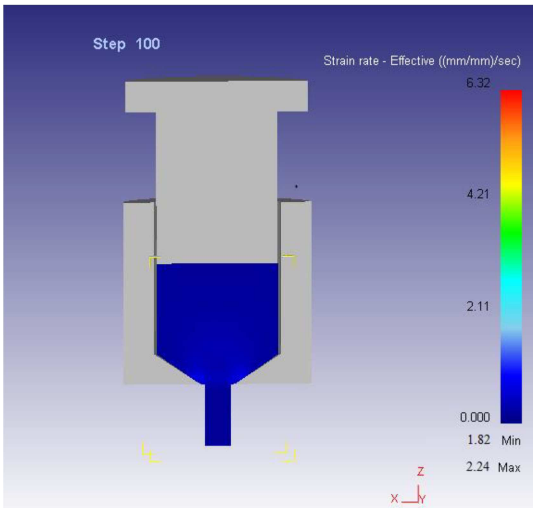


Figure 15. *Strain rate effective for 90% reduction cosine die profile.*

In Figure 13 has shown above the load prediction of the extrusion and the values of the extrusion load displayed on the graph is 1140N. Figure 14 has shown the uniform temperature distribution throughout the system but some temperatures loosed between top die and billet materials in the system.

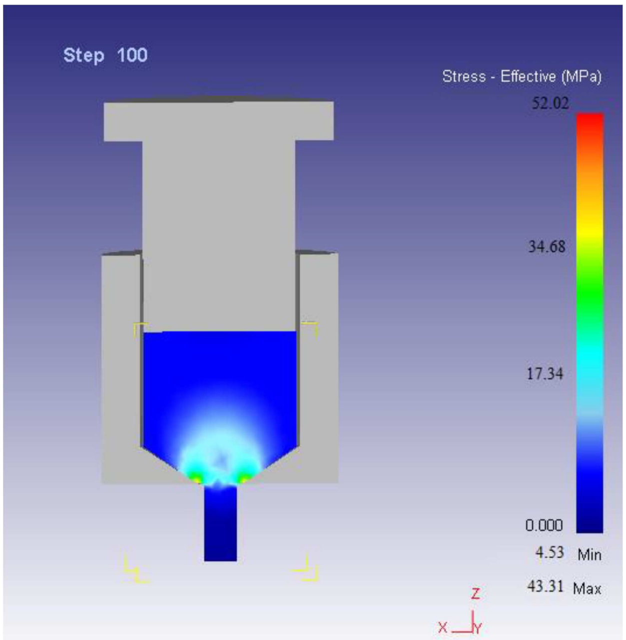


Figure 16. *Stress effective for 90% reduction cosine dies profile.*

Figure 15 has shown above the maximum and the minimum strain rate in 90% area reduction of cosine dies. The values are 2.24 and 1.82 ((mm/mm)/sec) respectively. Figure 16 shown above the maximum and minimum stress effectives on the extrusion process and the values is given 43.31and 4.53MPa respectively. The yellow and blue colors are shown the maximum and minimum stress effectives respectively.

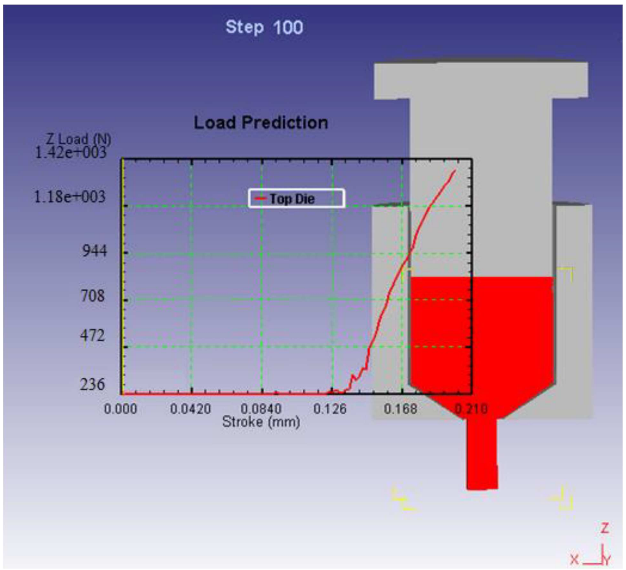


Figure 17. *Load prediction for 90% reduction cosine dies profile.*

In Figure 17 has shown below the load prediction of the extrusion and the values of the extrusion load displayed on the graph is 1360N. Figure 18 has shown the uniform temperature distribution throughout the system but some temperatures loosed between top die and billet materials in the system.

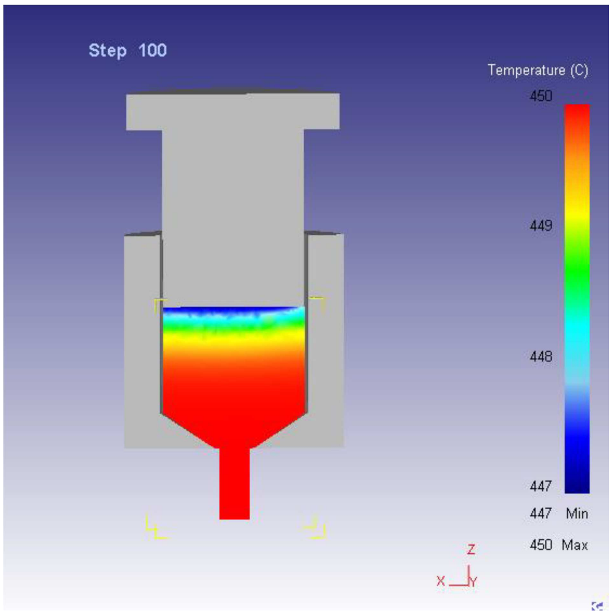


Figure 18. *Temperature for 90% reduction cosine dies profile.*

Extrusion simulation and post-processing in 3rd order polynomial Dies at different area reductions

Figure 19 has shown above the maximum and the minimum strain rate in 30% area reduction of 3rd order polynomial dies. The values are 2.41 and 1.85 ((mm/mm)/sec) respectively. Figure 20 shown above the maximum and minimum stress effectives on the extrusion process and the values are given 6.35 and 2.83MPa respectively. The yellow and blue colors are shown the maximum and minimum stress effectives respectively.

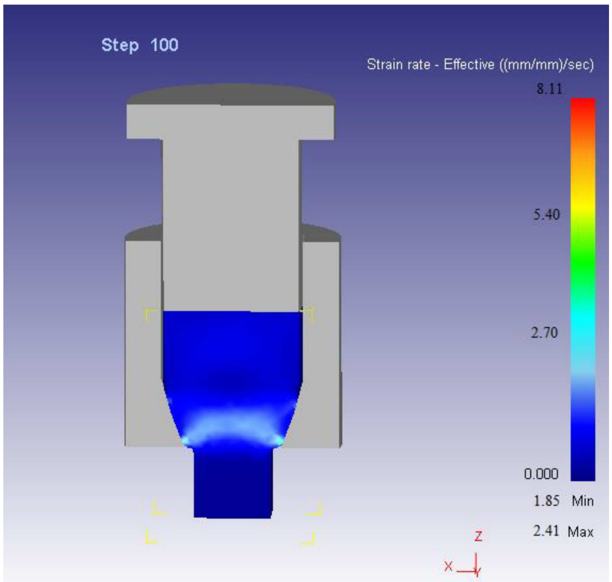


Figure 19. *3rd order polynomial dies strain rate effective (30%).*

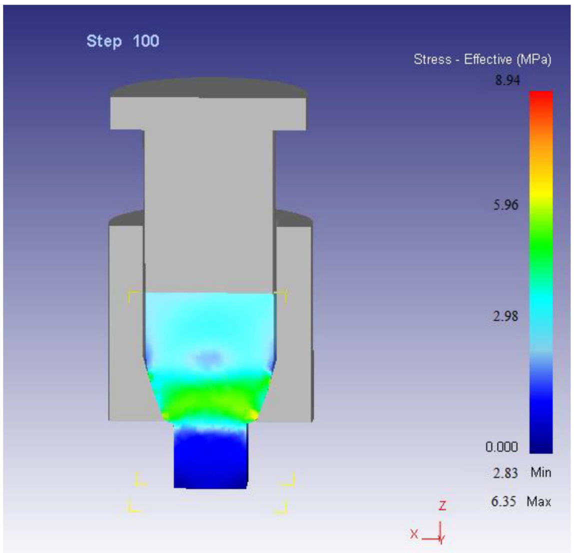


***Figure 20.** 3rd order polynomial dies stress effective (30%).*

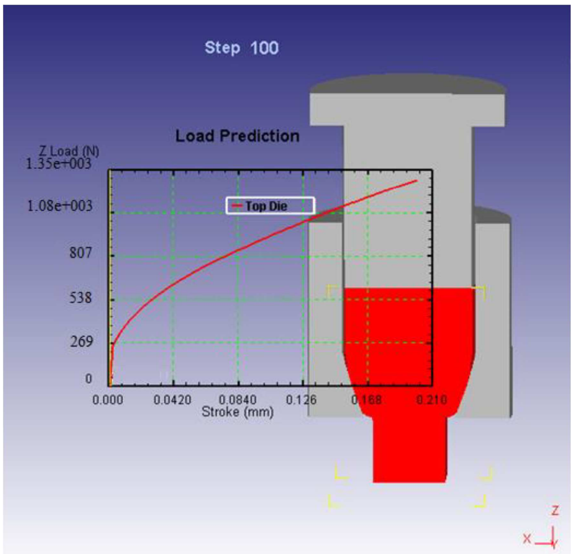


***Figure 21.** 3rd order polynomial dies load prediction (30%).*

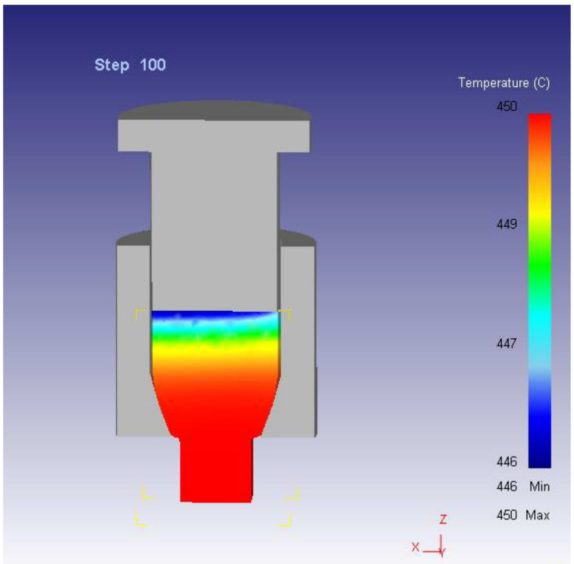


***Figure 22.** 3rd order polynomial dies Temperature (30%).*

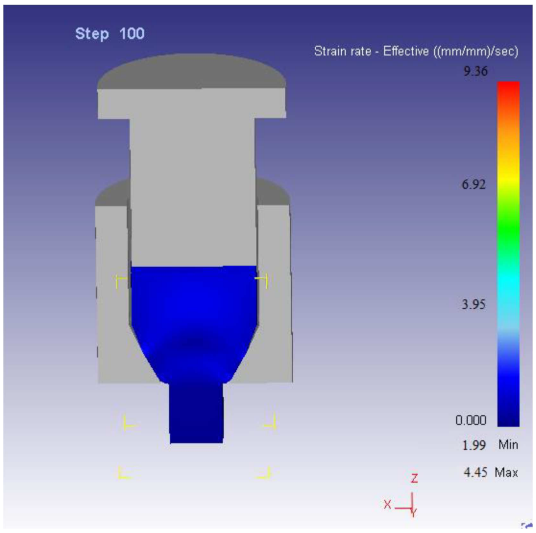


***Figure 23.** 3rd order polynomial dies strain rate effective (60%).*

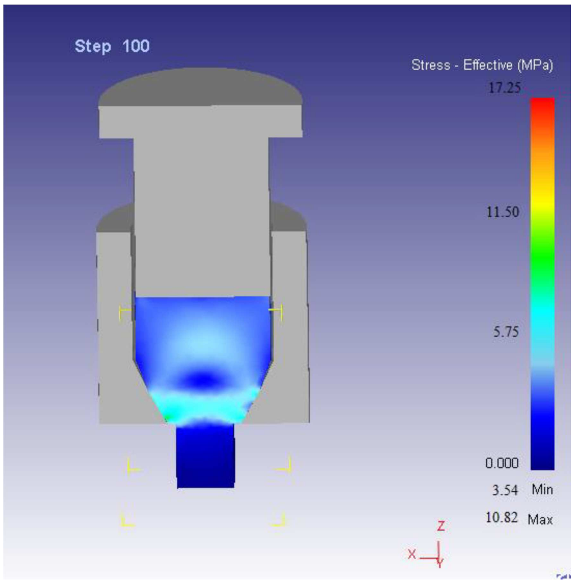


***Figure 24.** 3rd order polynomial dies stress effective (60%).*

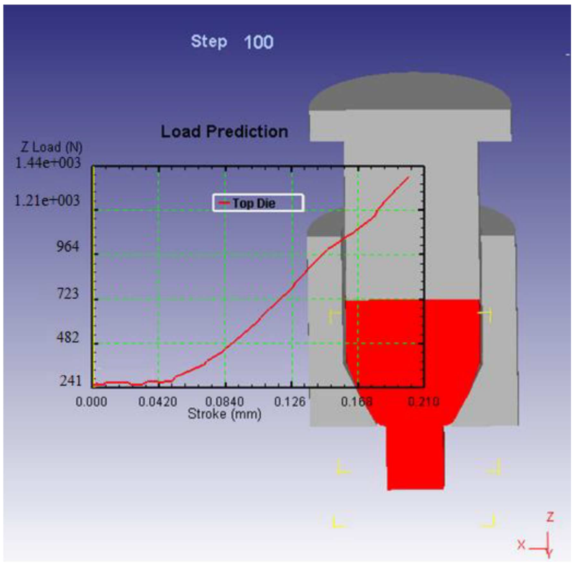


***Figure 25.** 3rd order polynomial dies load prediction (60%).*

In Figure 21 has shown above the load prediction of the extrusion and the value of the extrusion load displayed on the graph is 1290N. Figure 22 has shown below, the uniform temperature (450°C) distribution of the system and minimum temperature is developed at the punch and billet interaction surface which is 446°C.

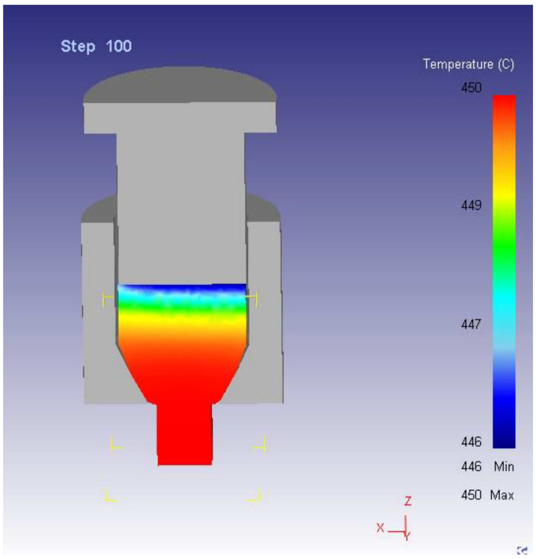


Figure 26. 3rd order polynomial dies Temperature (60%).

Figure 23 has shown above the maximum and the minimum strain rate in 60% area reduction of 3rd order polynomial dies and values are 4.45 and 1.99 ((mm/mm)/sec) respectively. Figure 24 shown above the maximum and minimum stress effectives on the extrusion process and the values are given 10.82and 3.54 MPa respectively. The green blue colors are shown the maximum and minimum stress effectives respectively. In Figure 25 has shown above the load prediction of the extrusion and the values of the extrusion load displayed on the graph is 1390N. Figure 26 has shown above, the uniform temperature (450°C) distribution of the system and minimum temperature is developed at the punch and billet interaction surface which is 446°C.

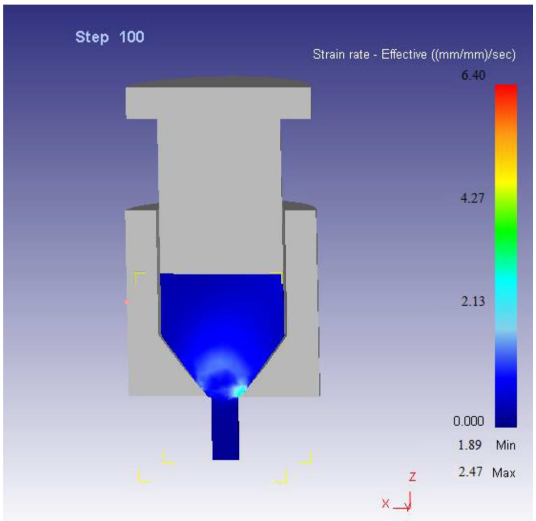


Figure 27. 3rd order polynomial dies strain rate effective (90%).

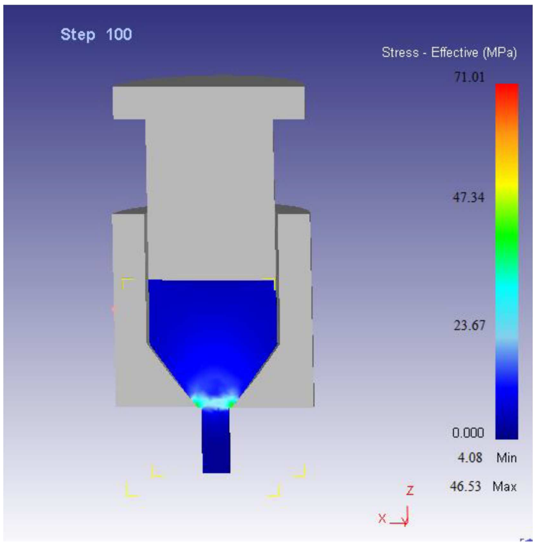


Figure 28. 3rd order polynomial dies stress effective (90%).

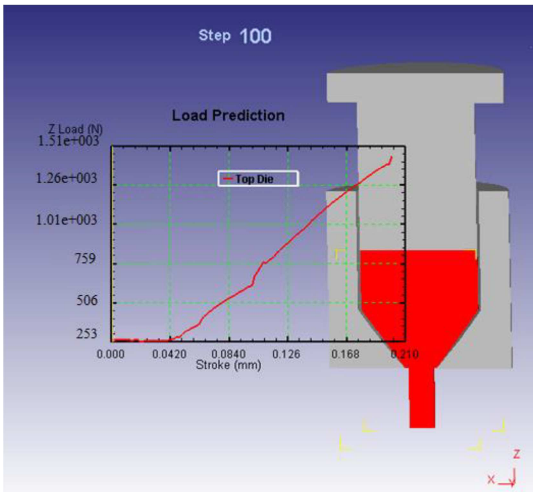


Figure 29. 3rd order polynomial dies load prediction (90%).

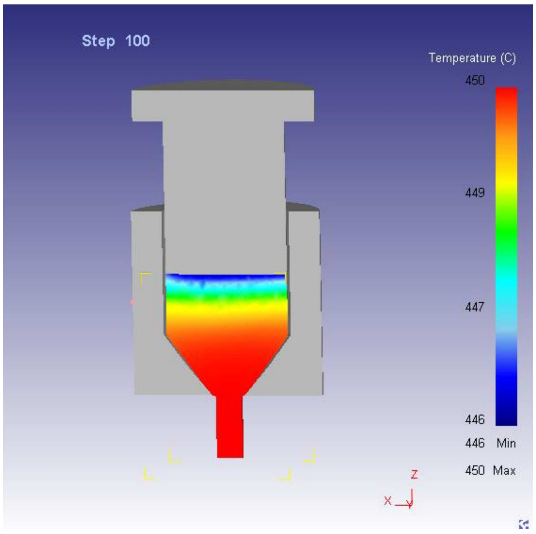


Figure 30. 3rd order polynomial dies Temperature (90%).

Figure 27 has shown above the maximum and the minimum strain rate in 90% area reduction of 3rd order polynomial dies.

The values are 2.47 and 1.89 ((mm/mm)/sec) respectively. Figure 28 shown above the maximum and minimum stress effectives on the extrusion process and the values are given 46.53 and 4.08MPa respectively. The green and blue colors are shown the maximum and minimum stress effectives respectively.

In Figure 29 has shown above, the load prediction of the extrusion and the values of the extrusion load displayed on the graph is 1460N. Figure 30 has shown above, the uniform temperature (450°C) distribution of the system and minimum temperature is developed at the punch and billet interaction surface which is 446°C.

5. Result and Discussion

Results in different reduction conditions are compared with cosine die and 3rd order polynomial die profiles. In cosine and 3rd order polynomial die profiles are taken three different % of area reduction such as: - 30%, 60% and 90%. From this area reduction there were three different extrusion load and effective stress for both cosine and 3rd order polynomial die profiles.

5.1. Upper Bound Analysis Results

Upper bound method is used to analysis the analytical results and the values are shown below tables and graphs.

Table 3. *Effective stress and load at different % of area reduction.*

Area reduction %	Effective stress (MPa)	Extrusion load (N)
30	4.0111	878.59
60	9.2148	1155.91
90	45.9697	1441.61

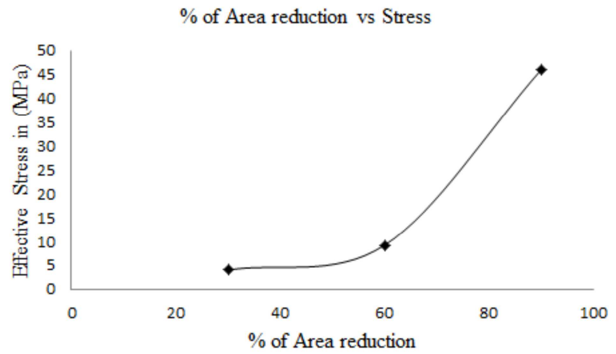


Figure 31. *Cosine dies effective stress at different % of area reduction.*

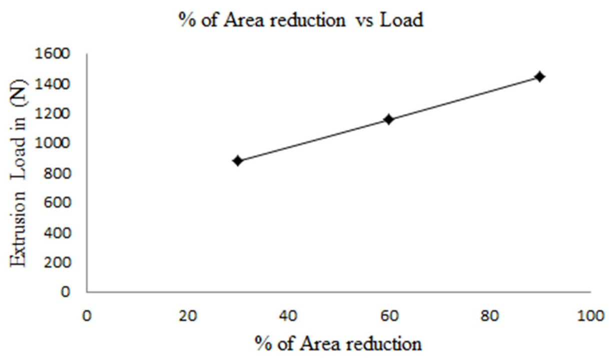


Figure 32. *Cosine dies extrusion load at different % of area reduction.*

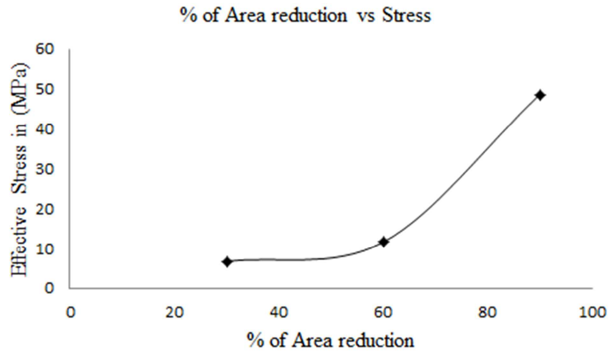


Figure 33. *3rd order polynomial dies effective stress at different % of area reduction.*

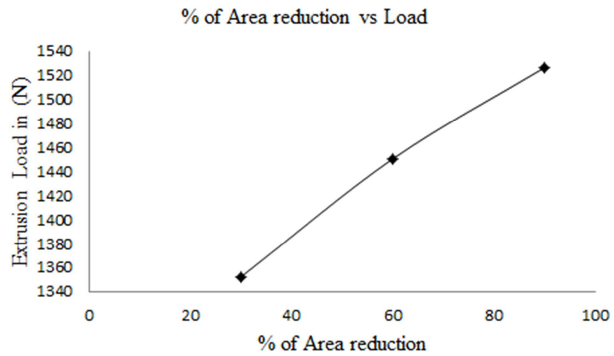


Figure 34. *3rd order polynomial dies extrusion load at different % of area reduction.*

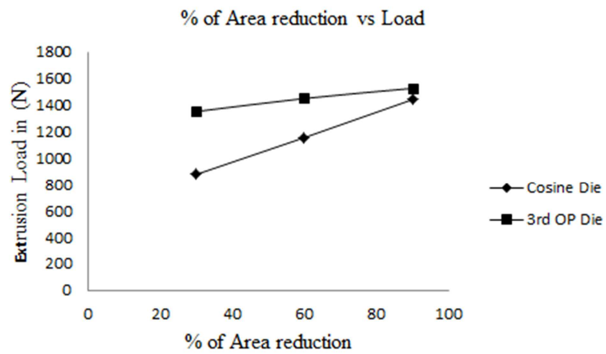


Figure 35. *Cosine and 3rd order polynomial dies extrusion load at different % of area reduction.*

Table 4. *3rd order polynomial dies Effective stress and load at different % of area reduction.*

Area reduction %	Effective stress (MPa)	Extrusion load (N)
30	6.6772	1352.20
60	11.5635	1450.52
90	48.6709	1526.32

In cosine die profile the stress effective is minimum on 30% of area reduction and maximum on 90% of area reduction. For 3rd order polynomial die profile is similar with cosine die but the value is maximum as compared as cosine die and shown above in Figures 31 and 34 respectively.

The extrusion load is increased with increased the percentage of area reduction for both dies as shown in Figure 35 and the minimum extrusion load is existed in cosine die profiles. In 3rd order polynomial dies the area reduction is increased from initial to end of the extrusion process. Due to this reason, the deformation is higher than the cosine dies and it needed higher extrusion load to extrude Al6063/20%SiC billet from initial to end of the process.

5.2. Numerical Analysis Results

DEFOEM 3D is used to analysis numerical values and the results are shown below.

Table 5. *Effective stress and load at different % of area reduction cosine dies.*

% of Area reduction	Effective stress (MPa)	Extrusion load (N)
30	3.82	820
60	8.74	1140
90	43.31	1360

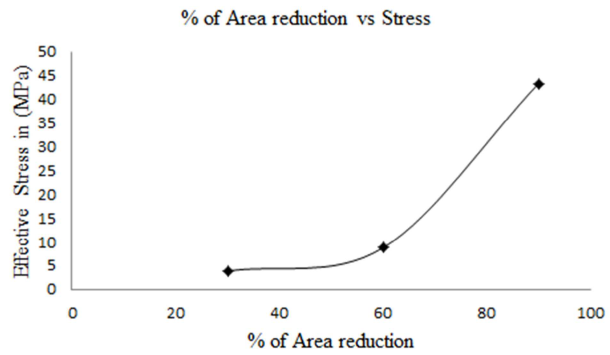


Figure 36. *Cosine dies effective stress at different % of area reduction.*

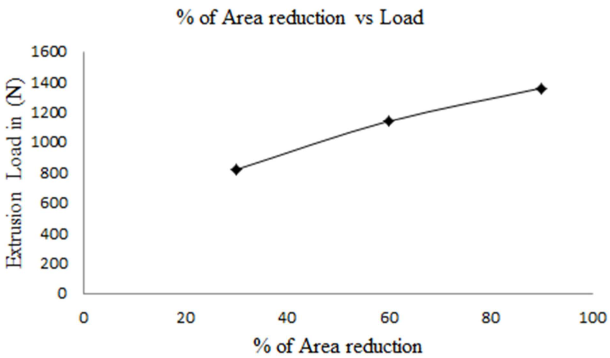


Figure 37. *Cosine dies extrusion load at different % of area reduction.*

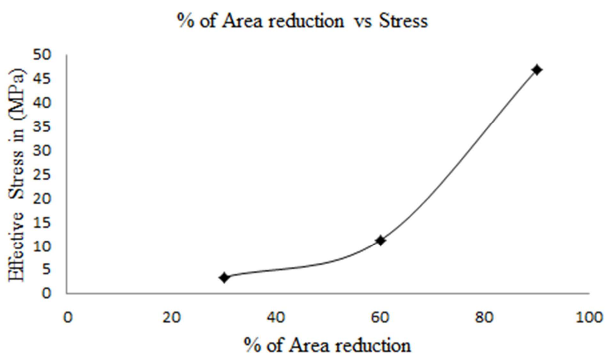


Figure 38. *3rd order polynomial dies effective stress at different % of area reduction.*

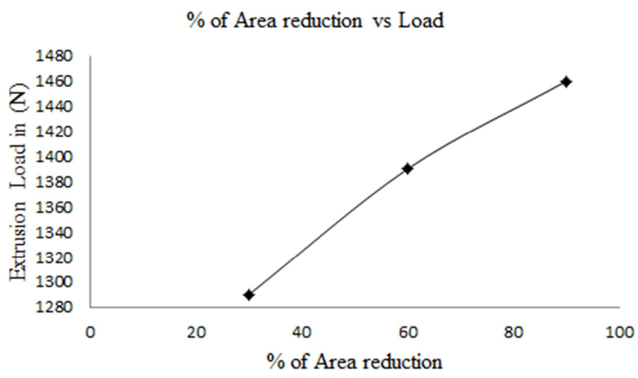


Figure 39. *3rd order polynomial dies extrusion load at different % of area reduction.*

Table 6. *3rd order polynomial dies Effective stress and load at different % of area reduction.*

Area reduction%	Effective stress (MPa)	Extrusion load (N)
30	3.34	1290
60	11.1	1390
90	46.8	1460

Generally, in cosine die profile the stress effective is minimum on 30% of area reduction and maximum on 90% of area reduction. For 3rd order polynomial die profile was similar with cosine die but the value of 3rd order polynomial die is maximum and shown above in Figure 36 and 38 respectively. The value of cosine die stress effective is lower than 3rd order polynomial die profiles. The extrusion load is increased with increased the percentage of area reduction for both dies as shown above in Figure 37 and Figure 39 the minimum extrusion load is existed in cosine die profiles.

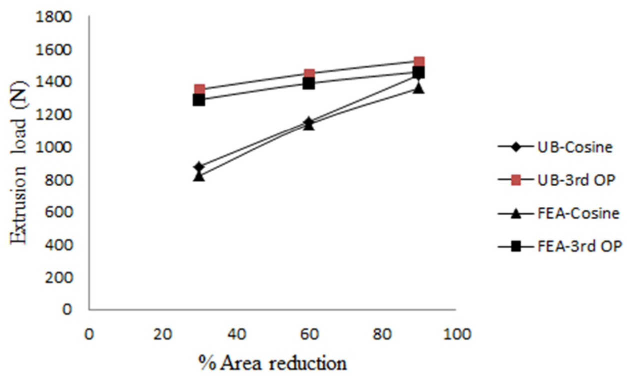


Figure 40. *Analytical and Numerical Extrusion Load at different % of area reduction.*

Figure 40 above shown analytical and numerical extrusion load at different % area reduction and the results of FEA is minimum values as compare the analytical result values. Generally, due to its low deformation power loss, the cosine die extrusion load is minimum value as compare analytical and numerical analysis results. The cosine die is used as the extrusion load for Al6063/20%SiC composite billet materials. Specially, 30% area reduction cosine die profile has minimum extrusion load as compare other area reduction of cosine and 3rd order polynomial dies and is better to extruded Al6063/20%SiC composite billet materials with optimum extrusion load.

6. Conclusion and Recommendation

6.1. Conclusion

1. For Al6063/20%SiC composite materials which are used to compare cosine and 3rd order polynomial dies to extrude the billet from circular to square shape.
2. The cosine die load increased with increased the % of area reduction and similarly, the 3rd order polynomial dies load increased with increased the % of area reduction.
3. The results of minimum extrusion load is developed in cosine die profiles as compare from the 3rd order polynomial dies for both analytical and numerical analysis.
4. Generally, cosine die profile is used as extrusion die for Al6063/SiC composite materials to optimum extrusion loads in different % of area reduction of square shape extruded. Specially, 30% area reduction cosine die profile has minimum extrusion load as compare other area reduction of cosine and 3rd order polynomial dies.

6.2. Recommendation

1. Cosine die profile could be used as extrusion die for Al6063/20%SiC composite materials to optimum extrusion loads in different % of area reduction of square shape extruded..
2. Specifically, could be used 30% area reduction of cosine die has minimum extrusion load from other five dies. Such as; cosine at 60% and 90% area reduction and 3rd order polynomial dies at three different % area reductions. So it used to extrude Al6063/20%SiC composite billet materials with optimum extrusion load.

Acknowledgements

First of all my deep gratitude goes to the almighty GOD for everything he did to me in all the way I path through, then after for my advisers Dr. C. Venkatesh including Mechanical Design and Manufacturing Engineering Department staff members for their continues and progressive support, advice and guide me to do better work and give me a reference materials and initiate me for my work. In addition, I would like to thanks Dr. PJR. to help for DEFORM 3D software and I would like to thank my classmates and friends for sharing their ideas and materials. In addition, I would like to thank my families to help for this study.

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