FINITE VOLUME ANALYSIS OF TWO-STAGE FORGING PROCESS FOR ALUMINIUM 7075 ALLOY

M. Vidya Sagar[a] and A. Chennakesava Reddy[b]
[a]Associate Professor, Department of Mechanical Engineering, JNTUH College of Engineering, Hyderabad - 50085
[b]Professor, Department of Mechanical Engineering, JNTUH College of Engineering, Hyderabad - 50085

Abstract: Two-stage (upsetting and finish operations) forging has been carried out using finite volume process. It was observed that the maximum stresses are greater in finish operation than those in upsetting operation. It was also concluded that the maximum die force increases as the initial temperature of the billet decreases.

Keywords: forging, upsetting, aluminium 7075 alloy, finite volume analysis.

Address all correspondence to:

1. INTRODUCTION

Forging is a plastic deformation process. In forging, simple billet geometry is transformed into a complex geometry by applying required pressure on material with the aid of forging machines such as hammers and presses.

In open die forging, at least one of the workpiece surfaces deforms freely. Open die forgings can be made with repeated blows in an open die, where the operator controls the workpiece in the die. During the forming process, as the height of the workpiece is decreased, cross-section area is increased by the rule of material volume conservation [1]. In closed die forging operations, flash, the excess material to the outside of the dies may occur and high tool stresses are generated [2].

In hot forging process, billet is heated above its recrystallization temperature. Greater deformation is attained, die wear is reduced and dimensional accuracy is low in hot forging process. In warm forging process, billet is heated to a temperature which is between its recrystallization temperature and work hardening temperatures. Warm forging process provides products with better dimensional tolerances than hot forging process although forging loads and die wear is greater. On the other hand, in cold forging process, billet is forged usually at the room temperature. Cold forging improves mechanical properties and greater dimensional accuracy is achieved. However, higher force is necessary in cold forging process [3].

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The usage of process simulation programs is common for research and development of forging processes. By using this type of programs, forging tool designer could decrease costs by improving achievable tolerances, increasing tool life, predicting and preventing flow defects, and predicting part properties [4].

2. GEOMETRIC MODELING

Finite volume method is a simulation method in which the grid points are fixed in space and the elements are simply partitions of the space defined by connected grid points. The finite volume mesh is a fixed frame of reference. The material of a billet under analysis moves through the finite-volume mesh; the mass, momentum, and energy of the material are transported from element to element. The finite-volume solver, therefore, calculates the motion of material through elements of constant volume, and therefore no remeshing is required. The most common finite volume software used in forging is MSC SuperForge to predict to forging variables [5].

3-D modeling of the part and dies has been realized by using PRO/ENGINEER Wildfire 3.0 [6]. In the simulation process, aluminum forging in different temperatures for the modeled part has been investigated and proper forging stages have been defined to fill the forging dies without any defects by using finite volume method (FVM) with sfForming 8.0 module of Simufact 3.0 [7]. The technical drawing of forging die is given in figure 1 and its 3-D model is given in figure 2.

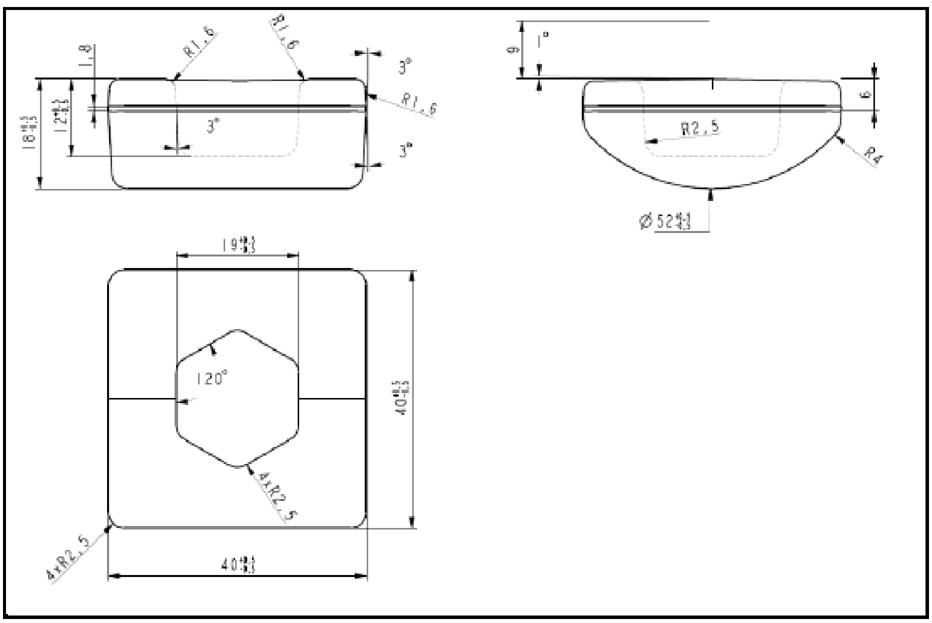

Figure 1: Part drawing

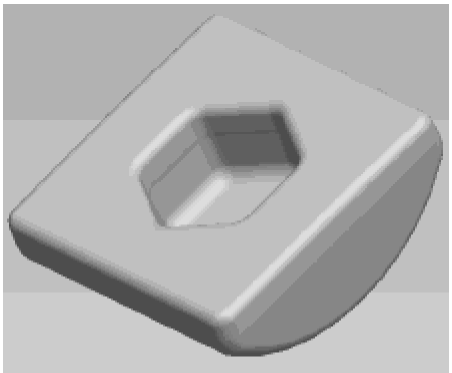

Figure 2: Solid modeling of the forging

The parting line is located at the 5.1 mm from the top of the forging part as shown in figure 3 since parting line is always located along the largest cross-section.

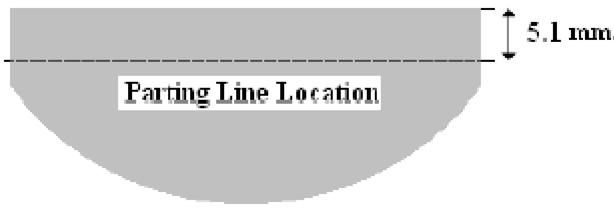

Figure 3: Parting line location on the forged part

The flash thickness is defined for the plan area of the forging. Plan area, at square cross-section of the part along the parting line, is calculated as 1600 mm^2 since one edge of the square is 40 mm. The minimum recommended flash thickness for the plan area less than 6500 mm^2 is given as 0.8 mm for aluminum forging alloys. However, the flash thickness, i.e. the face clearance between upper and lower die, is taken as 1.8 mm by considering an additional 1 mm for the safety of the forging operation to avoid any clash of the upper and lower dies as can be shown in Figure 4.

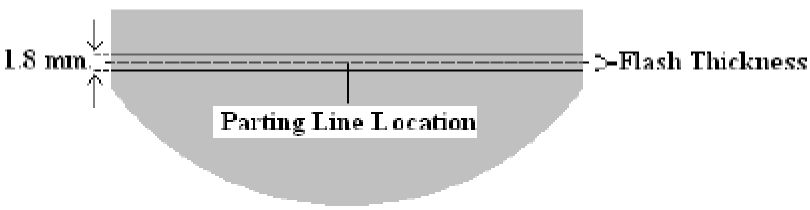

Figure 4: Flash thickness on the forged part

After defining location of the parting line and value of the flash thickness, the draft angles of 3° are applied to the outer surface of the part and to hexagonal hole on the part. A bottom draft of 1° is provided for the upper surface of the part to prevent the sticking the part to the upper die at the bottom of stroke and to remove the part easily. The application of draft is shown in figure 5.

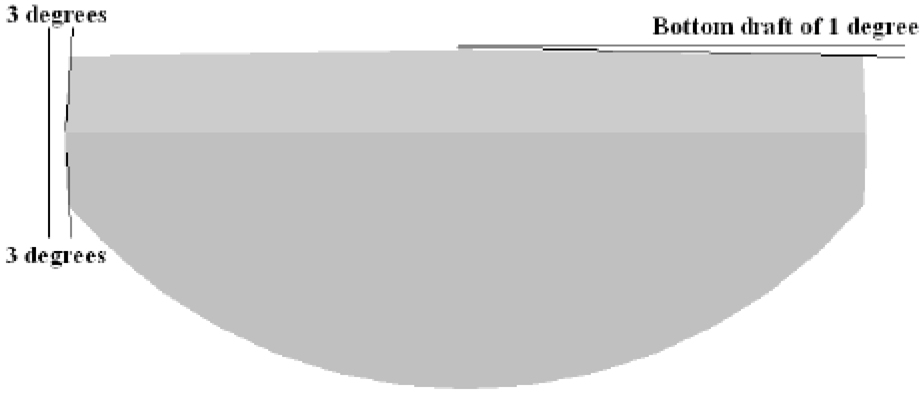

Figure 5: Draft angle on the forged part

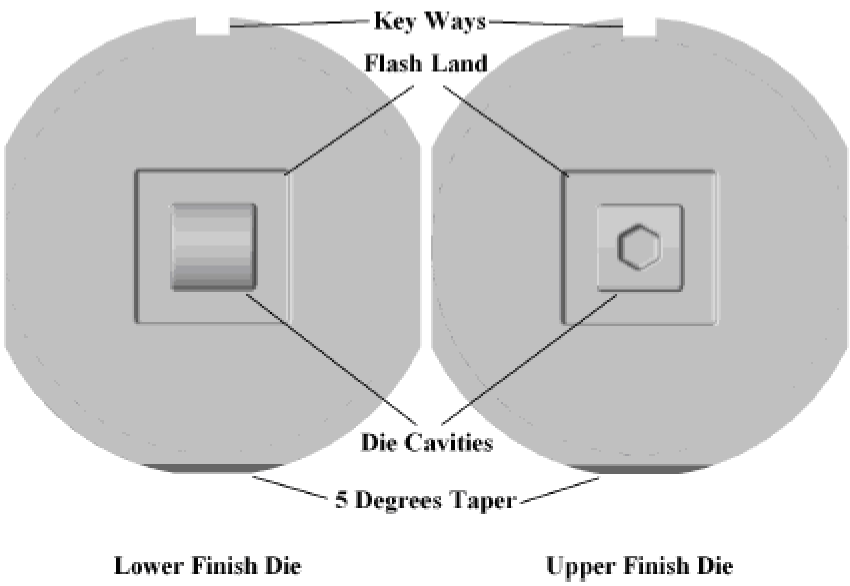

Figure 6: Lower and upper finish dies

According to the constraints of the die holder, the upper and the lower dies in the finish stage are designed based on the designed part geometry. In design of the upper and lower dies, a shrinkage allowance of 1.5 % is taken since some shrinkage occurs after the forged part cools. Total height of the upper and lower die is 200 mm by considering the flash thickness when the press is at the bottom dead center. The dies are designed by considering 99.1 mm in height and by adding flash thicknesses of 1.8 mm, the total height of the dies becomes 200 mm. As seen in figure 6, the flash land is provided at the circumference of the die cavity. Since the die housing at the middle is going to be used for the finish stage, the upper and lower finish dies will have an external diameter of 222 mm. The key ways are also modeled with 16 mm in width and 9 mm in depth to prevent the rotational motion of the dies relative to the die holder. The gutter is not designed since it is not used in the finish die.

2.1 Definition of Process

Process type may be selected as "open die" or "closed die" forging. After selecting process type, it should be noted that forging process is "hot forging", simulation is 3-D and the used solver is finite volume. The models of upper and lower die geometries from CAD program are imported to the finite volume program in "stl" (i.e. stereo lithography) format after the process type is defined. The billet dimension is selected according to part volume with considering flash volume as given in table 1. By using the mass properties module of CAD program, the part volume is found as 20657 mm^3.

Table 1: Geometry and dimensions of billet

Geometry of billet	Dimensions of billet
Cylindrical	30 mm in diameter
	32 mm in height

2.2 Assignment of Material Properties

The dies are considered as rigid die with heat conduction. 7075 aluminum alloy is chosen because this material is extensively used in aerospace, automotive and defense industry with its high strength, low density, and low cost. The flow stress-strain relation for hot forging temperatures is given by

Flow stress, $\sigma_f = C(\dot{\varepsilon})^m$ (1)

where, C is the yield constant

$\dot{\varepsilon}$ is the strain rate

m is the strain rate hardeninf component.

Tensile yield strength 7075 aluminium alloy is $\sigma_t = 103$ MPa and Ultimate tensile strength is $\sigma_{uts} = 228$ MPa at room temperature. Poisson's ratio is 0.33. Density is 2800 kg per m^3. Thermal conductivity is 172 Watt/ m-^{0}K. Specific heat is 960 Joule/ kg-^{0}K. Coefficient of thermal expansion is 2.50x10^{-5}. Solidus temperature is 476 ^{0}C and melting temperature is 635 ^{0}C.

2.3 Initial Temperature of Billet and Dies

Initial temperatures of the billet are taken as 375 ^{o}C, 400 ^{o}C, 425 ^{o}C and simulation is made for these temperature values. Initial temperature of the dies is assumed as 200 °C. other parameters used in this work are given below:

Room temperature	= 25 ^{0}C,
Emissivity	= 0.25,

Ambient heat transfer coefficient = 50 Wt/ m^2-^{0}K, and
Workpiece heat transfer coefficient = 600 Wt/ m^2-^{0}K

2.4 Coefficient of Friction

Friction between die and billet is an important consideration in a metal forming process. Such friction produces a tangential (shear) force at the interface between die and billet which restricts movement of the material and results in increased energy and press forces. The magnitude of the shear friction stress influences the deformation pattern, temperature rise, the tool deflection and total force in metal forming. In this study, plastic shear friction is used with a coefficient of 0.2 since high loads are applied in forging operations.

2.5 Definition of Press

Schematic illustration of the crank press is shown in figure 7. Crank radius of the press is 110 mm; rod length is 750 mm; and speed of revolution is 100 rpm.

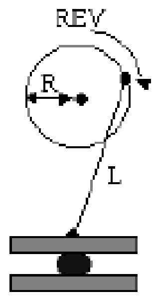

Figure 7: Schematic representation of crank press.

4.4.6 Finite Volume Meshing

Element size in finite volume program should be assigned for the billet. Billet element size is 1 mm. number of output divisions are 21. The finite volume ratio is 0.2. The stroke length depends on billet dimension.

5. FORGING PROCESS BY FINITE VOLUME METHOD

Different finite volume simulations are made to ensure to proper forging operation without any defects. Forging operation is firstly thought as single operation and analysis are made for the single operation.

The billet is placed on the upsetting die at the horizontal position and the upsetting operation is applied and then the finish forging operation is performed in the finish die. Position of the billet on the upsetting die and the finish die are shown in figure 8. In this orientation, the billet is upset to 18.5 mm in height and width of the part in x-direction becomes 37.4 mm and width of the part in y-direction becomes 38.5 mm as shown in Figure 9.

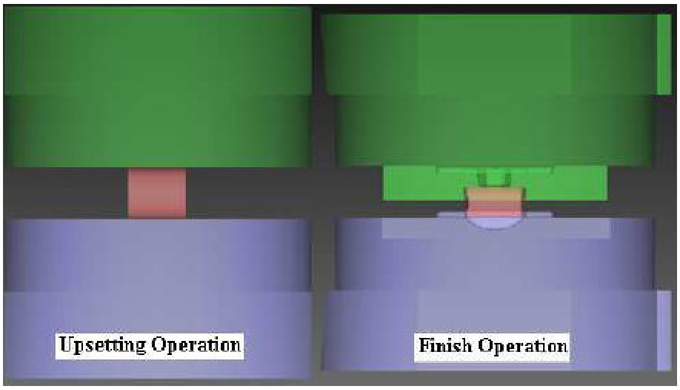

Figure 8: Position of billet on the upsetting die and finish die.

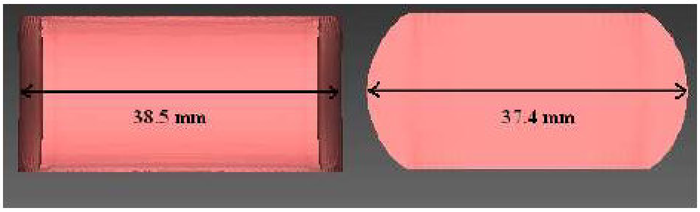

Figure 9: Dimensions of billet after forging operation.

The die is completely filled in the finish operation as seen in figure 10 and the flash distribution is more uniform. No fold is observed during the forging operation.

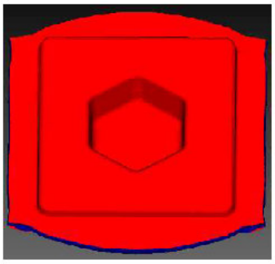

Figure 10: Die filling during forging operation.

6. RESULTS AND DISCUSSION

In the finite volume analysis, 25512 finite volume elements are created for the upsetting operation while 24997 finite volume elements are created for the finish operation and the simulation time is measured nearly 3 hours 15 minutes for the upsetting operation while the simulation time is nearly 2 hours for the finish operations for a workstation with 10 GHz processor and 100 GB RAM.

After finite volume simulation of the forging operation, the force requirement, stress values and part temperature after the upsetting and the finish forging operations can be obtained by the finite volume program.

As stated previously, the simulations have been made for the forging temperatures of 375 °C, 400 °C and 425 °C and simulation results are given in Table 2.

Table 2: Maximum die force and stress for forging of 7075 Al-alloy

Temperature of billet (°C)	Die force for upsetting (Ton)	Die force for finish (Ton)	Maximum stress for upsetting (MPa)	Maximum stress for finish (MPa)
375	7.5	32.0	101.2	110.0
400	7.4	29.1	99.8	108.4
425	6.3	26.2	87.6	95.2

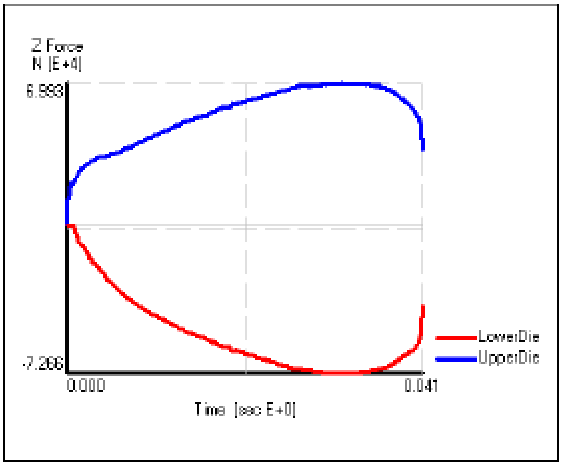

Figure 11: Die force for upsetting operation.

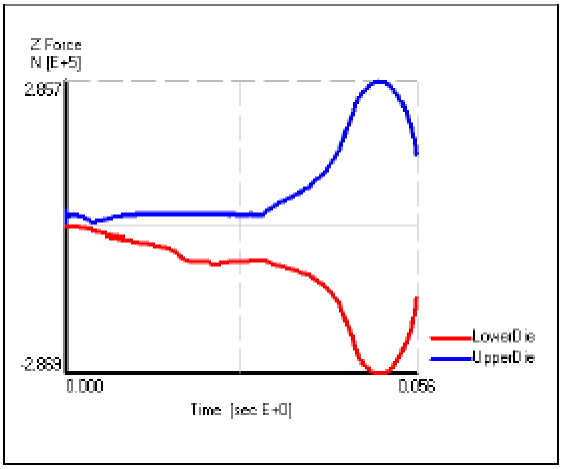

Figure 12: Die force for finish operation.

In the die force diagrams, the force is given as a function of time as shown in figure 11. The force increases almost linearly for the upsetting operation.

The force slightly increases initially for the finish operation as revealed in figure 12. At the beginning of the finish operation upsetting occurs and later the force increases dramatically and reaches the maximum value to complete the forming.

The maximum stress distributions are shown in figures 13 and 14 for upsetting and finish operations. The red color represents the highest stress value and the blue the lowest value. The maximum stress occurs in the loading regions where the lower and the upper die contact with the workpiece at first time. The maximum stress values are relatively higher in finish operation since deformation is much more in finish operation.

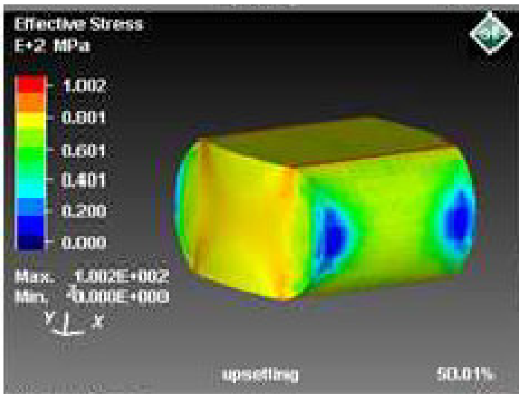

Figure 13: Maximum stress distribution for the upsetting operation at 400 °C

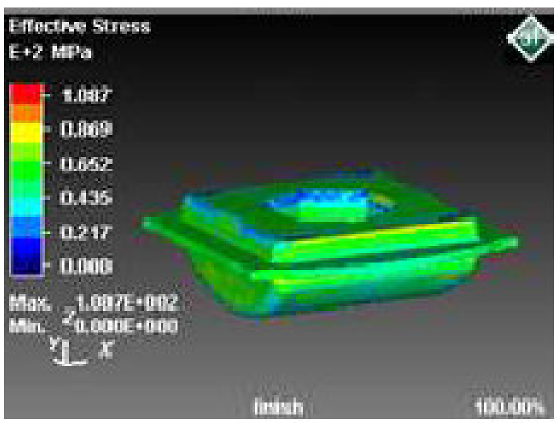

Figure 14: Maximum stress distribution for the finish operation at 400 °C

The temperature distributions are shown figures 15 and 16 for upsetting and finish operations. It is seen that the maximum temperature occurs at the zones where the maximum deformation happens throughout the forging operation. The temperature values at the end of the upsetting process are directly transferred to the finish operation.

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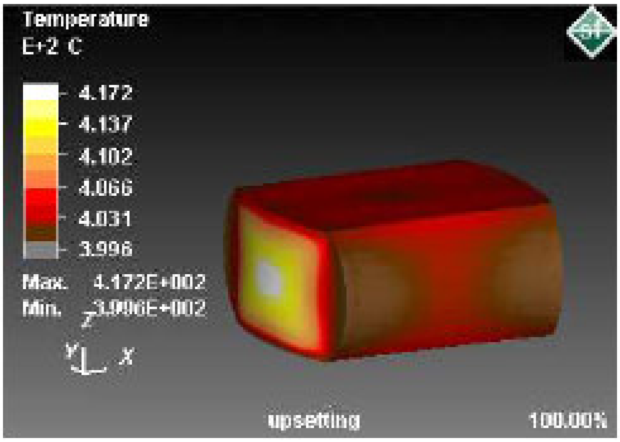

Figure 15: Temperature distribution for upsetting operation at 400 °C

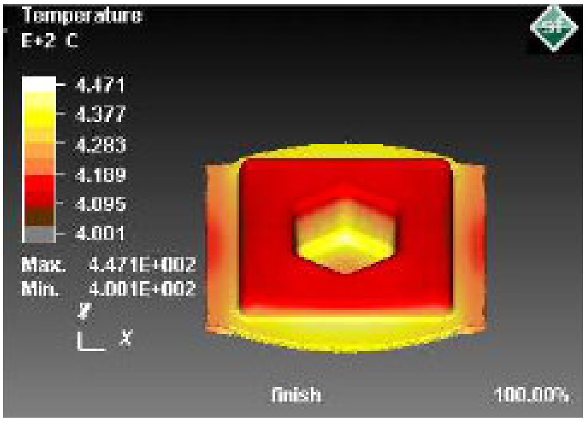

Figure 16: Temperature distribution for finish operation of at 400 °C

The stress on the workpiece decreases as the initial temperature of the billet increases. The maximum stress occurs during the initial contact of the lower and the upper die with the workpiece. The maximum die force increases as the initial temperature of the billet decreases. The die forces slightly increase at the beginning of the finish forging and then the die forces increases rapidly to fill the die cavity completely.

The workpiece temperatures increase during the upsetting and finish forging operations and the maximum temperatures occur at the zones where the deformation on the part is high. The temperature rise is much higher in low forging temperatures which can be attributed to close die and billet temperatures at the low forging temperatures. As a result of this, there is less heat loss to the dies from the part.

7. CONCLUSION

The following conclusions are drawn from the forging operations of 7075 Al-alloy:

1. The force increases almost linearly for the upsetting operation.
2. The maximum stress occurs in the loading regions where the lower and the upper die contact with the workpiece.
3. Maximum stresses are greater in finish operation than those in upsetting operation.
4. The maximum temperature occurs at the zones where the maximum deformation happens.
5. The stress on the workpiece decreases as the initial temperature of the billet increases.
6. The maximum die force increases as the initial temperature of the billet decreases.

8. ACKNOWLEDGEMENTS

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