A modular approach for the estimation of forging load for the closed die forging process by computer simulation

Dipakkumar Gohil and Mahendrakumar Maisuria

***Abstract*—** Closed die forging is a very complex process and the measurement of actual forces for real material is difficult and cumbersome. Hence the computer simulation modeling technique has been adopted to get the estimated load requirement. The objective of this research work is to simulate and analyze the closed die forging process. In this research paper, an attempt has been made to compute the load requirement in the closed die forging process by using computer simulation during different stages of the process. The results of simulation have been compared with the actual load requirement and the deviation of estimated load and actual load has been reported in the form of percentage error. If the percentage error is more than the permissible limit then the necessary corrective measures are recommended to get the better simulation results.

***Keywords*—** Closed die forging, H/D ratio, Modeling, Modular approach, Simulation.

I. INTRODUCTION

IN the present highly competitive era, the mass production requirements in the engineering industries have increased the demand for forged components. Forging process, usually involve multiple pre-forming processes followed by a specified finishing process. Process simulation has become an increasingly important tool for the development of new or improved processes. With simulation tools the costs and the time necessary for the development of new products could be reduced significantly. The process requires a lot of experience and skill to optimize the quality, costs and lead time [1].

The objective of this research work is to simulate and analyze the closed die forging process. The main focus is to estimate the load requirement for the die cavity filling at different stages of forging of AISI 1016 by a computer simulation technique. The closed die forging process has been divided in to two stages i.e. deformation process before flash formation and after flash formation [2].

The designs based on results of simulation are required to be evaluated to make sure that the material would flow as per the requirement in the die cavity [3].

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II. MODELING OF FORGING

The modeling and simulation of closed die forging process has been carried out by using analytical and numerical methods [7], [4]. For the purpose of simulation, a cylindrical shape billet having different H/D ratio have been deformed between two die halves as shown in Fig. 1. The deformation process before flash formation has been depicted in Fig. 2 where as Fig. 3 represents the deformation process during the flash formation stage.

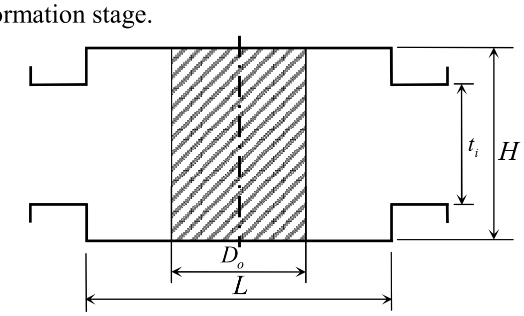


Fig. 1 Billet and Die geometry: Initial configuration

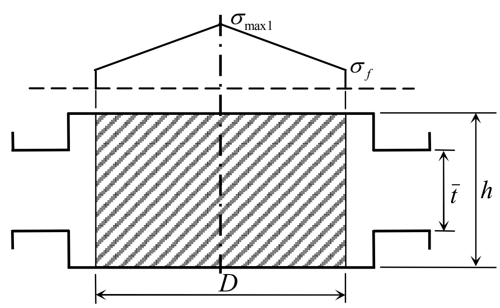


Fig. 2 Billet and Die geometry: Upsetting

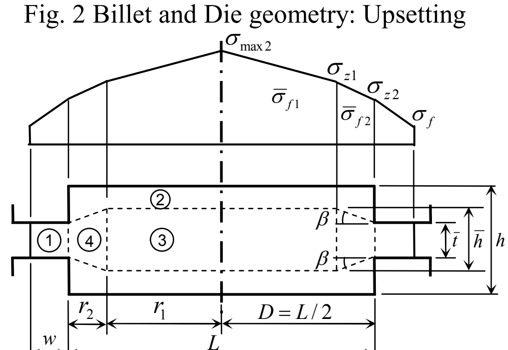


Fig. 3 Billet and Die geometry: with Flash

A. Estimation of Flow Stresses

Forging is a deformation process which involves several variables interconnected by more or less complex function. The method discussed here, used to simulate the hot die forging process to determine the stresses and the load. The flow stress relationship has been implemented as a subroutine [13], [14], [19].

$$\sigma_f = C\dot{\varepsilon}^m \tag{1}$$

Where,

$C = f(\varepsilon,\ T)$

The parameters *C* and *m* are available in the material property hand books for different billet materials used in various types of forming processes.

B. Calculation of Strain

The strains in the die cavity as well as in the flash during different stages have been calculated as follows [9], [16].

The strain before flash formation, as shown in Fig. 2, could be computed as,

$$\varepsilon = \ln(H/h) \tag{2}$$

During flash formation, as depicted in Fig. 3, the strain in flash, indicated as zone 1, may be calculated as,

$$\varepsilon_1 = \varepsilon_{tc} + \ln(\overline{t}_c/\overline{t}) \tag{3}$$

At the end of forging, the material is assumed to flow in to flash by shearing along the surface indicated by dashed line in Fig. 3. Therefore the strain in zone 2 i.e. ε_2 is equal to ε_{tc} which is the zone between the shearing line and the die, and the strain in zone 3 is ε_3 may be computed zone as,

$$\varepsilon_3 = \varepsilon_{tc} + \ln(\overline{h}_c/\overline{h}) \tag{4}$$

$$\overline{h} = 0.8\overline{t}(L/2\overline{t})^{0.92} \tag{5}$$

The mean height of the convergence region 4 as shown in Fig. 3, could be calculated as,

$$\overline{h}_1 = (\overline{h} + \overline{t})/2 \tag{6}$$

The strain in the convergence region 4 may be obtained as,

$$\varepsilon_4 = \varepsilon_{tc} + \ln(\overline{h}_c/\overline{h}_1) \tag{7}$$

C. Calculation of Strain Rate

The strain rates for the various stages of closed die forging are calculated according to the following:

Stage I: Deformation process before flash formation as shown in Fig. 2 may be computed as,

$$\dot{\varepsilon} = v/h \tag{8}$$

Stage II: Deformation process after Flash formation as depicted in Fig. 3 may be evaluated as,

$$\dot{\varepsilon}_1 = v/\overline{t} \tag{9}$$

$$\dot{\varepsilon}_3 = v/\overline{h} \tag{10}$$

$$\dot{\varepsilon}_4 = v/\overline{h}_1 \tag{11}$$

D. Stress Calculation

The stress before flash formation as shown in Fig. 2 may be computed as,

$$\sigma_{\max 1} = \sigma_f(1 + (\mu_1 D/h)) \tag{12}$$

The stresses after flash formation as represented in Fig. 3 could be calculated as,

$$\sigma_{z2} = 2\mu_1\sigma_f(w/\overline{t}) + \sigma_f \tag{13}$$

$$\sigma_{z1} = (K_2/K_1)\ln(\overline{t}/K_3 + K_2 r_2)) + \sigma_{z2} \tag{14}$$

$$\sigma_{\max 2} = ((2\mu\sigma_{f1}r_1)/h) + \sigma_{z1} \tag{15}$$

Where,

$K_1 = -2\tan\beta$

$K_2 = -\sigma_{f2}K_1 + 2\mu_2\sigma_{f2}(1 + \tan^2\beta)$

$K_3 = \overline{h} - r_2 K_1$

$\tan\beta = [1 - \{((\overline{h}/\overline{t}) - 1)/((\overline{h}/\overline{t})\ln(\overline{h}/\overline{t}))\}]^{1/2}$

E. Calculation of Force

The force required for deformation process before flash formation for the geometry as shown in Fig. 2 could be,

$$F_I = 2\pi\sigma_f[(h^2/4\mu_1^2)(\exp(D/h) - 1) - hD/4\mu_1)] \tag{16}$$

The force required for deformation process after flash formation for the geometry as shown in Fig. 3 would be,

$$F_{II} = F_1 + F_2 \tag{17}$$

Where,

$F_1 = 2\pi\sigma_{z1}[(\overline{h}^2/4\mu_2^2)(\exp(\mu_2 L/\overline{h}) - 1) - \overline{h}L/4\mu_2)]$

$F_2 = \sigma_f(\pi/4)(2Lw + w^2)(1 + (\mu_1 w/3\overline{t}))$

F_1 is the average force on the billet and F_2 is the average force on the flash land.

III. The Modular Approach

In the modular approach, the part geometry may be divided in to eight basic regions as shown in Fig. 4, The eight regions are divided in such a manner that, as the top surface descends vertically, as a result of an external force of unit velocity, the inner and outer surfaces of the rings move inward or outward from the axis as shown in Fig. 4 and 5.

The boundaries of these regions may be considered as either rigid tools or as rigid parts of adjacent elements of the work piece. For each of these eight regions shown, a general admissible velocity field may considered as shown in Fig. 4 and 5 for rectangular and triangular flow; both inward and outward, which could be given as below. The parameters A, B, R, z, and α are defined in Fig. 6. $\dot{u} = du/dt$ and $\dot{w} = dw/dt$ are the radial and axial velocities, respectively.

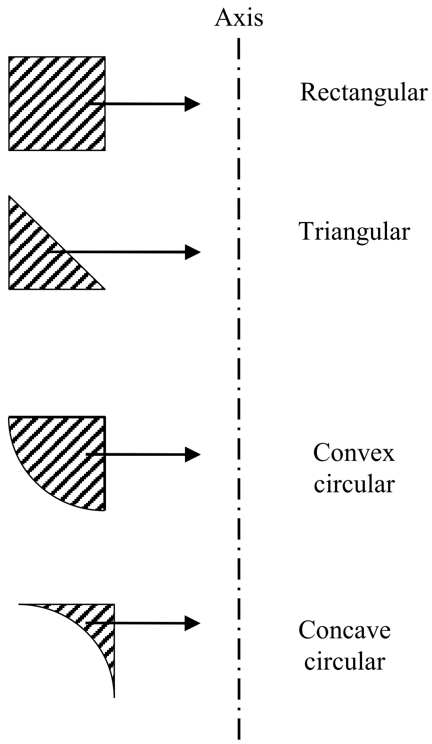


Fig. 4 Inward flow of modules

A. Rectangular flow inward

$$\dot{u} = -(1-R^2)/2AR \tag{18}$$

$$\dot{u} = -(1-B)(1-R)/2AR \tag{19}$$

$$\dot{w} = -z/A \tag{20}$$

$$\dot{w} = (1-B)z/2AR \tag{21}$$

B. Rectangular flow outward

$$\dot{u} = (R^2-B^2)/2AR \tag{22}$$

$$\dot{u} = (1-B)(B+R)/2AR \tag{23}$$

$$\dot{w} = -z/A \tag{24}$$

$$\dot{w} = (1-B)z/2AR \tag{25}$$

C. Triangular flow inward

$$\dot{u} = -\cot\alpha(1+(1/R))/2 \tag{26}$$

$$\dot{w} = (z\cot\alpha/2R)+1 \tag{27}$$

D. Triangular flow outward

$$\dot{u} = \cot\alpha(1+(1/R))/2 \tag{28}$$

$$\dot{w} = -(z\cot\alpha/2R)+1 \tag{29}$$

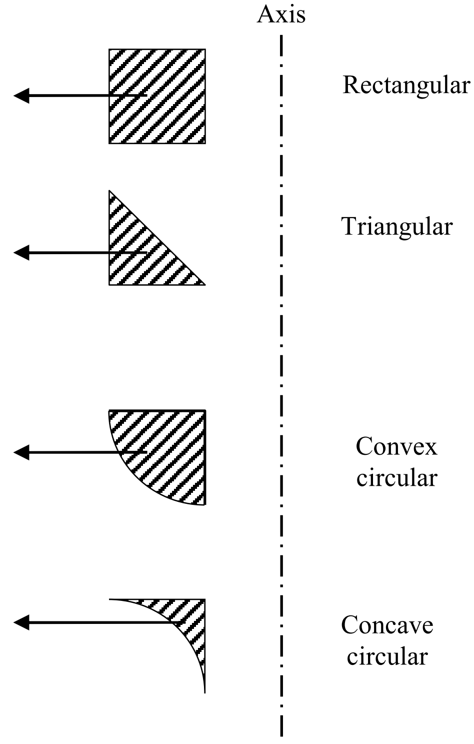


Fig. 5 Outward flow of modules

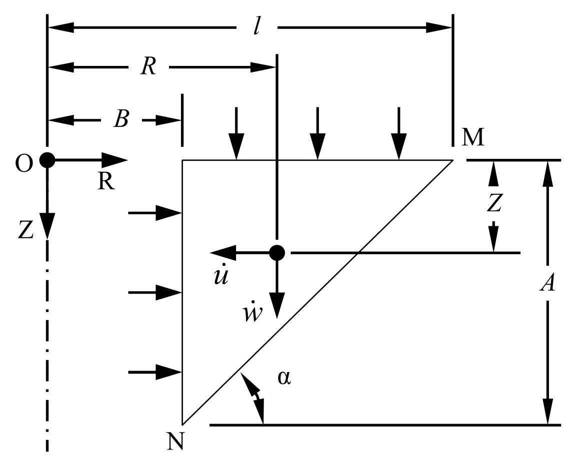


Fig. 6 Definition of various parameters

Once the velocity components for any of the eight basic regions are known then the strain rates could be evaluated as,

$$\dot{\varepsilon}_R = \delta\dot{u}/\delta R \tag{30}$$

$$\dot{\varepsilon}_Z = \delta\dot{w}/\delta R \tag{31}$$

$$\dot{\varepsilon}_\theta = -(\dot{\varepsilon}_R + \dot{\varepsilon}_Z) \tag{32}$$

$$\dot{\gamma}_{RZ} = (\delta\dot{u}/\delta z + \delta\dot{w}/\delta R) \tag{33}$$

The rate of internal energy dissipation would be calculated for the field under consideration could be as follows:

$$\dot{E} = (\sqrt{2}/3)\sigma_f \int (\dot{\varepsilon}_R^2 + \dot{\varepsilon}_\theta^2 + \dot{\varepsilon}_Z^2 + (\dot{\gamma}_{RZ}^2/2)dV + \sigma_f \int_S m\dot{S}ds \tag{34}$$

The first volume integration in (40) has to be carried out throughout the entire volume of the part geometry and the second surface integration is required to be carried out for over all surfaces. When considering the total rate of energy dissipation may be represented as,

$$\dot{E}_t = \sigma_f \sum_{i=1}^{i=n} e_i A_i V_i \tag{35}$$

The following Fig. 7 represents a modular approach applicable to a typical forging component geometry.

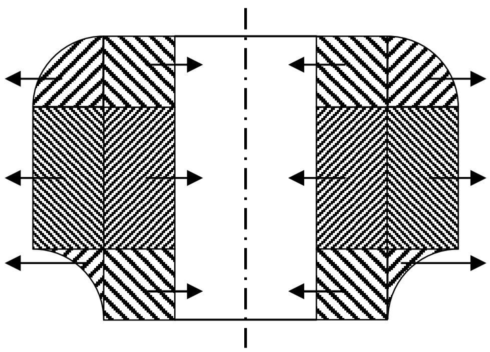


Fig. 7 Application of a modular approach

Fig. 7 depicts a typical component made by closed die forging process and the different modules e.g. Rectangular, Triangular, Concave circular, and Convex circular are represented by different hatch pattern.

Fig. 8 shows an application of the modular approach for the closed die forging of connecting rod of an Internal Combustion Engine [1], [12].

Fig. 8 Connecting rod of an Internal Combustion Engine

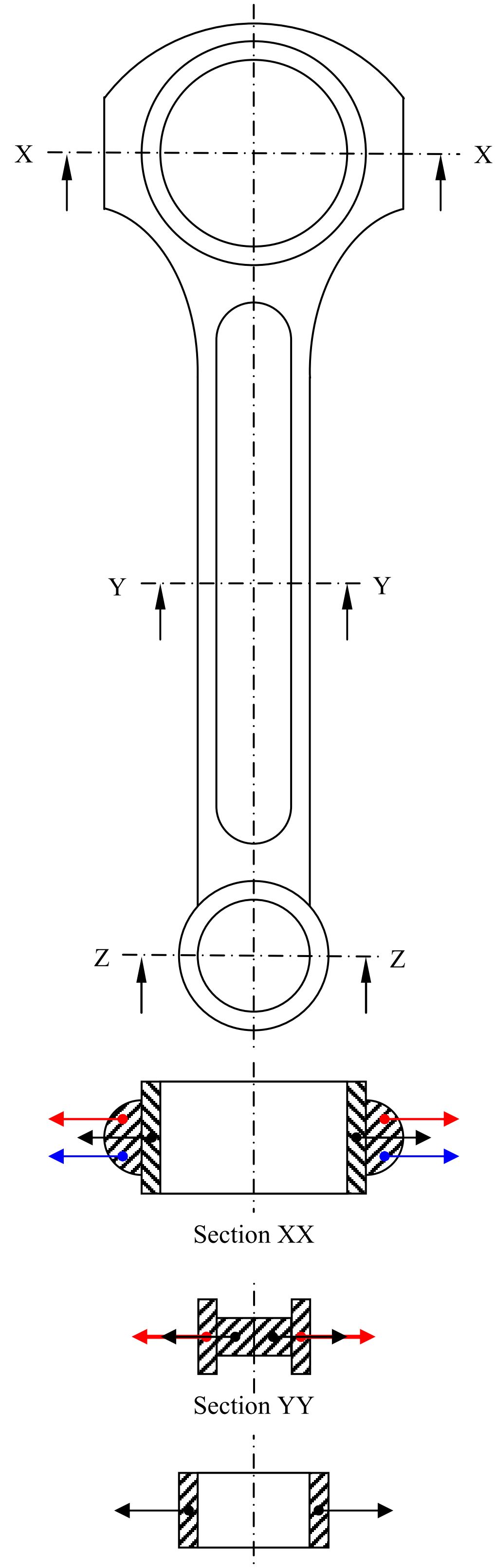
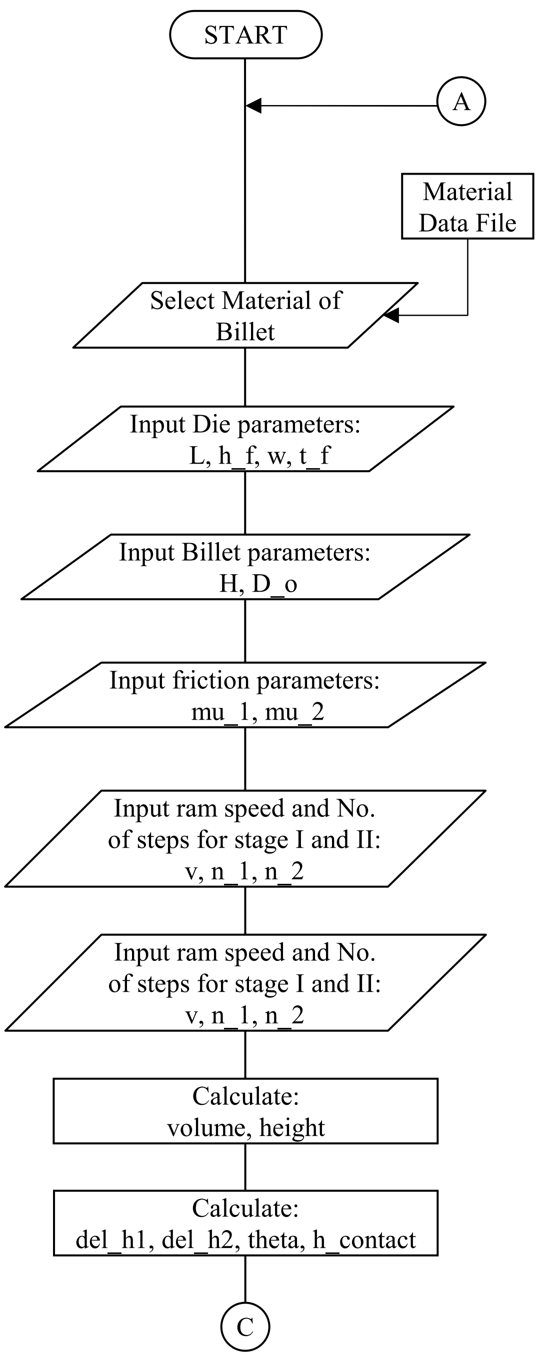


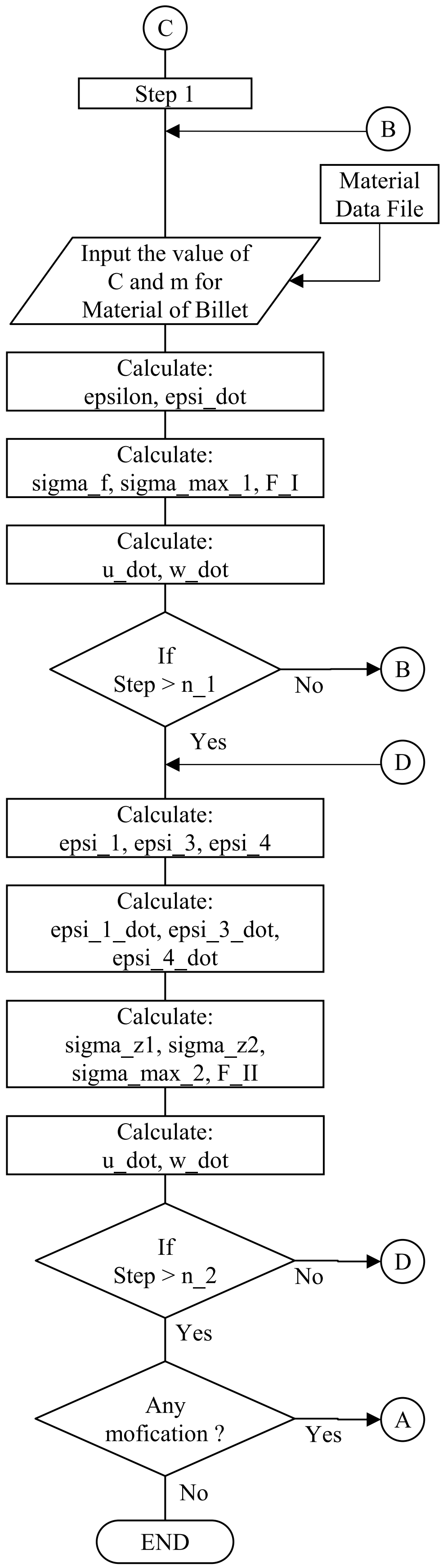
Fig. 9 Sectional details of Connecting rod

IV. Simulation Algorithm

A computer simulation algorithm has been developed consisting of separate subroutines for the two different stages of forging process i.e. deformation process before flash formation and after flash formation [5].

For the process simulation, initially the material is required to be selected from the material data base. The die parameters, billet parameters, number of stages of deformation process are required to be provided then the algorithm starts computations and simulations using computer graphics as per coding [11].





The computer code generates step by step the results for the various output parameters e.g. height, diameter, strain, strain rate, flow stress, and load requirement. At the end of the simulation, the algorithm asks for any modifications, if any, may be change of material or dimensions for the purpose of next computations and simulation.

V. Results and Discussion

Fig. 10, 11, and 12 shows the graph of Actual Load (kN), Estimated Load from computer simulation (kN) and % error plotted against the Stroke length (mm) for the H/D ratio of 1.9, 1.4, and 1.0 respectively for the flash thickness of 2 mm [18].

From the Fig. 10, 11, and 12, it could be clearly seen that, as the stroke proceeds, the load requirement for the deformation increases. At a particular stroke length, the increase in the load is steep; this is the point where the flash formation starts. The stroke length for flash formation to start is different for different H/D ratio. As the H/D ratio decreases, the billet diameter is required to be increased to maintain the constant volume of the billet material. The actual load and estimated load have been plotted and are in good agreement for all the cases studied as shown in Fig. 10, 11, and 12.

The value of percentage error between actual load requirement and the estimated load for the H/D ratio of 1.9 varies from 1.12 % to 4.14 %. For the H/D ratio of 1.4, the percentage error ranges from 1.21 % to 3.72 %. The percentage error for the H/D ratio of 1.0 has been found to vary between 2.01 % to 4.51 %.

Further, it has been observed that as the H/D decreases the amount of % error which is also termed as the deviation from the actual load requirement reduces which has been observed with H/D ratio of 1.9 and 1.4. It may be anticipated that the difference between actual load requirement and the load requirement obtained by computer simulation should further reduce for H/D ratio of 1.0 but it is found to be increased therefore further investigation in the actual process as well as in the computer simulation is required, to know the effect of various process governing parameters.

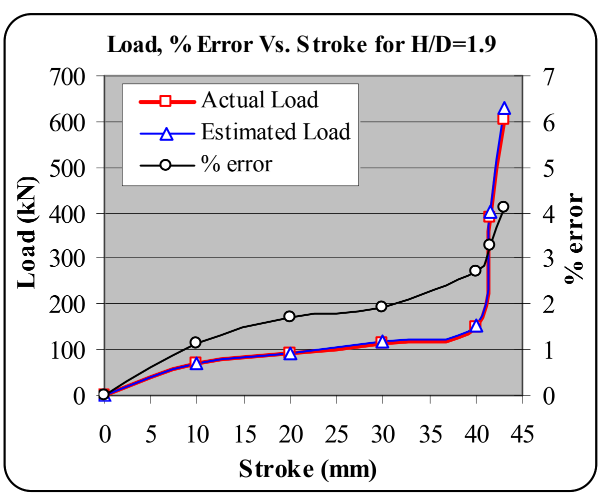


Fig. 10 Load (kN), % error Vs. Stroke (mm) for H/D = 1.9

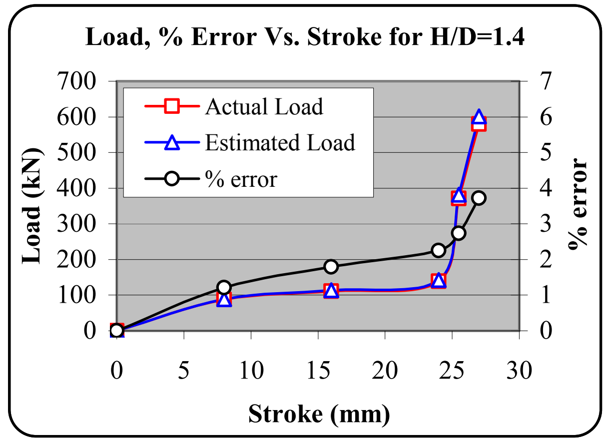


Fig. 11 Load (kN), % error Vs. Stroke (mm) for H/D = 1.4

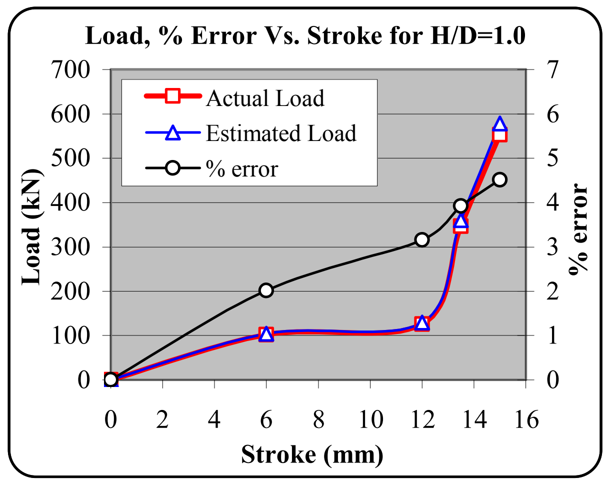


Fig. 12 Load (kN), % error Vs. Stroke (mm) for H/D = 1.0

VI. Conclusion

Finally, it may be concluded that the success of the simulation technique to estimate the deforming load requirement for the closed die forging operation would depend upon the following:

- The selection of material parameters from the material property database should match with the actual metallic material. If the percentage error is more than 10 % then the material properties are required to be obtained by the suitable material testing method.
- The friction conditions prevailing between the die and billet material during the actual deformation process and the simulation are required to be nearly same.
- Accuracy of the simulation would be governed by the parameters such as the H/D ratio, strain rate, the flow of material in the die cavity, and strain hardening property of the actual material.

However, due to the complexity of forging operations, the material and process condition, the manufacturing by forging process is still a very much dependent upon trial runs, which results into increased lead-time. An integrated forging simulation and optimization approach would significantly improve the overall process of the components manufactured by closed die forging process.

NOMENCLATURE

C	Strain hardening constant
D_o	Initial diameter of billet
F_I	Force required before flash formation
F_{II}	Force required after flash formation
H	Initial height of billet
$\bar{h}$	Current height of billet
$\bar{h}_c$	Average height of shearing zone at the beginning of flash formation
$\bar{h}_1$	Current average height of shearing zone
L	Die diameter
m	Strain rate sensitivity exponent
T	Temperature
t_i	Initial distance between flash lands of two die halves
$\bar{t}$	Flash thickness
$\bar{t}_c$	Flash Thickness at the beginning of flash formation
$\dot{u}$	Velocity along the horizontal direction
v	Ram speed
w	Flash width
$\dot{w}$	Velocity along the vertical direction
β	Shear plane angle
σ_f	Flow stress
$\sigma_{\max 1}$	Maximum stress before flash formation
$\sigma_{\max 2}$	Maximum stress after flash formation
ε	Strain before flash formation
ε_1	Strain for zone 1
ε_3	Strain for zone 3
ε_4	Strain for zone 4
$\dot{\varepsilon}$	Strain rate before flash formation
$\dot{\varepsilon}_1$	Strain rate for zone 1
$\dot{\varepsilon}_3$	Strain rate for zone 3
$\dot{\varepsilon}_4$	Strain rate for zone 4
ε_{tc}	Strain at the beginning of the flash formation
μ_1	Coefficient of friction between die and billet
μ_2	Coefficient of shearing friction

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