

## Computational Analysis and Design for Precision Forging Of Aluminium AA 6061 Connector

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### ABSTRACT

Development of a new process methodology which satisfies given criteria is a big challenge faced by most of the forging industries. The domain of competition is quite large and hence every firm aims at producing near net shapes thereby eliminating the need for machining and other secondary operations. The present investigation deals with the flow simulation of Aluminium forgings conforming to AA 6061 specification and henceforth studies the mechanical characteristics of the flow simulation results. The Aluminium AA 6061 component considered is precision forged with a hydraulic press in a die having geometrical interlocking. During precision forging it was difficult to achieve the required net shape of the component because of unsymmetrical location of small ribs on cylindrical surface and variation in the cross sections from bottom to top (i.e. unsymmetrical about both X & Y axis). Thus to eradicate the problem encountered, the flow simulation of the precision forging process was carried out and the mechanical characteristics of the flow simulation results obtained were studied.

**KEYWORDS:** Flow simulation, Precision forging, Mechanical characteristics, Hydraulic press, Billet, Component.

### I. INTRODUCTION:

There has been a growing importance for precision forging of various components like Aluminium AA 6061 connector shown in Fig 1, which would otherwise have been produced by die casting processes or other metal forming processes that have many disadvantages compared to precision forging process [1]. Precision forging is a unique technique with a goal to produce a net shape, or at least a near-net shape, in the as-forged condition. The term net describes that no subsequent machining or a minimal of secondary finishing operations on the forged component is required. Thus, a net shape forging or precision forging process aims at minimizing the cost and waste associated with post-forging operations. Therefore, the final product from a precision forging needs little or no final machining. Significant cost savings are achieved from the optimized use of material, resulting in the overall reduction of energy consumption. Precision forging also requires less of a draft, i.e. 1° to 0°. However the downside of this process is its cost; therefore it is only implemented if significant cost reduction can be achieved [2-4]. The main problem for forging process is the high cost and long lead time for the design and production of tooling. For this purpose, CAD, CAM and CAE techniques are used to get faster results in the design and manufacture of tooling by decreasing the trial and error time to produce successful forgings [5]. CAD, CAM and CAE programs also develop satisfactory die design for the required process parameters. 3-D modeling of forging dies is usually made with the aid of CAD software such as Pro/ENGINEER, CATIA, and SOLID WORKS etc. If there are any problems in the simulation of the process then the designer of the forging process can easily change his design parameters in the CAD software packages [6]. The usage of process simulation programs is common for research and development of forging processes. By using this type of programs, forging tool designer can decrease costs by improving achievable tolerances, increasing tool life, predicting and preventing flow defects, part properties [7]. In this context it is proposed to carry out the flow simulation of the entire precision forging process and examine the flow simulation results obtained.

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 re-meshing is required [8]. The most common finite volume software's used in forging are MSC Super Forge and Deform 3D to predict the forging variables. Deform 3D is very supportive in optimizing the forging process and defining its parameters. Forging process can be simulated, Problems related with Product and Process design can be observed easily, Various dies can be tried and forging process can be analyzed closely by using Deform 3D. After a number of simulation processes involving different parameters, optimum die set for which the die cavity gets filled completely while maintaining a lower stress can be selected by using Deform 3D [9].

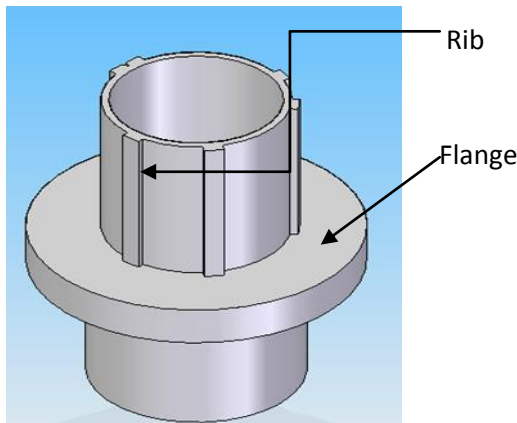


Fig 1 Model of the component

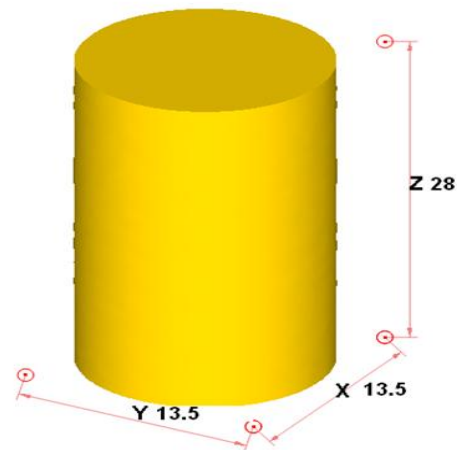


Fig 2 Aluminium AA 6061 billet

## II. MATERIAL AND METHODS:

The present investigation examines the intricacies involved in the precision forging of Aluminium AA 6061 billet as shown in Fig 2 into the component as shown in Fig 1. Aluminium alloy 6061 is one of the most extensively used of the 6000 series Aluminium alloys. It is a versatile heat treatable precipitation hardening extruded alloy containing magnesium and silicon as its major alloying elements with medium to high strength capabilities [10].

Element	Weight %
Aluminium (Al)	Min 96.4 to Max 97.9
Silicon (Si)	Min 0.40 to Max 0.8
Copper (Cu)	Min 0.15 to Max 0.40
Magnesium (Mg)	Min 0.8 to Max 1.2
Chromium (Cr)	Min 0.04 to Max 0.35
Manganese (Mn)	Min 0.04 to Max 0.15
Zinc (Zn)	Max 0.25
Titanium (Ti)	Max 0.15
Iron (Fe)	Min 0.15 to Max 0.7
Other elements not more than 0.05% each	0.15 total

Table 1: Composition of Aluminium AA 6061

## 2.1 Aluminium AA 6061

Aluminum AA 6061 is a silver white alloy that has a strong resistance to corrosion and like gold, is rather malleable. It is a relatively light metal compared to metals such as steel, nickel, brass, and copper with a specific gravity of 2.7. Aluminum AA 6061 is easily machinable and can have a wide variety of surface finishes. It also has good electrical and thermal conductivities and is highly reflective to heat and light, henceforth Aluminium AA 6061 alloy has wide applications ranging from aerospace to marine engineering [11].

## 2.2 T6 Temper Grade

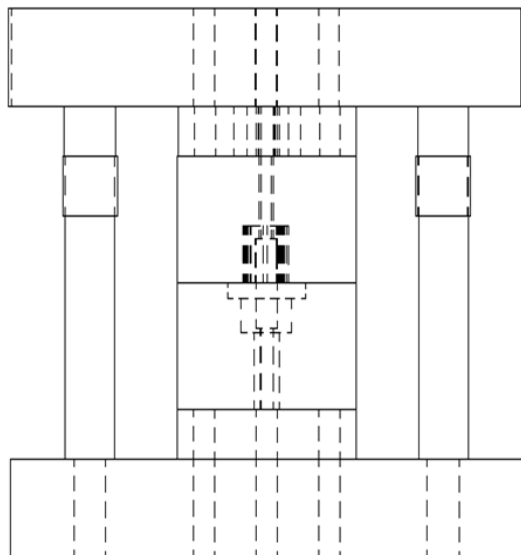
T6 temper Aluminium AA 6061 has an ultimate tensile strength of at least 42,000 psi (300 MPa) and yield strength of at least 35,000 psi (241 MPa). More typical values are 45,000 psi (310 MPa) and 40,000 psi (275 MPa), respectively. In thicknesses of 0.250 inch (6.35 mm) or less, it has elongation of 8% or more; in thicker sections, it has elongation of 10% [12]. The typical value of thermal conductivity for 6061-T6 at 80°C is around 152 W/m K. A material data sheet defines the fatigue limit under cyclic load as 14,000 psi (100 MPa) for 500,000,000 completely reversed cycles using a standard RR Moore test machine and specimen [13].

## 2.3 Flow simulation

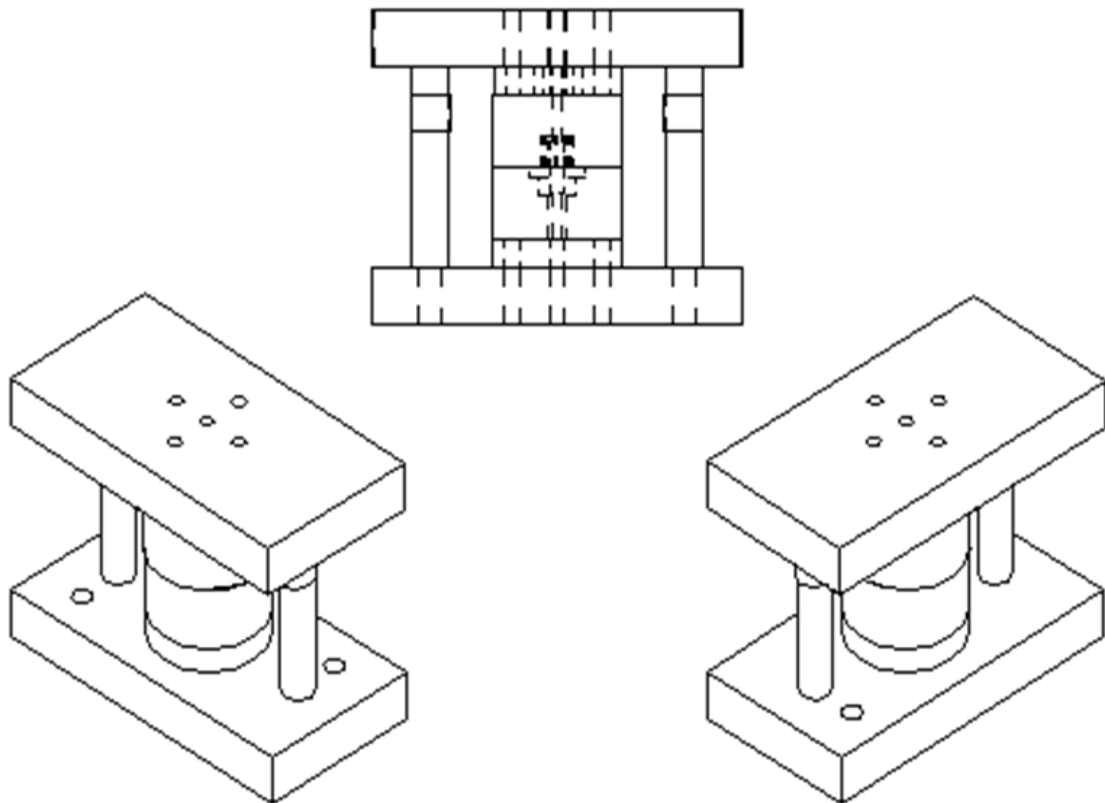
Flow simulation was carried out using Deform-3D software with the following additional information gathered for the purpose of simulating the whole process using the above mentioned software.

The additional information and parameters that were necessary for simulation were:

1. STP (STEP) and STL format of the model of the component. (I.e. Aluminium connector)
2. STP (STEP) and STL format of the models of the tool and die set as shown in Fig 3 and Fig 4.
3. Type of the press to be used (in the present investigation, we have considered Hydraulic press).
4. Configuration and characteristics of the press used.
5. Constant movement speed of the press.
6. Temperature of the forging operation (in the present investigation, we emphasize on precision forging which is usually done below recrystallization temperature, approximately room temperature i.e. cold forging conditions).



**Fig 3 Tool and die set used in the present investigation**



**Fig 4 Different views of the tool and die set used in the present investigation**

#### 2.4 Procedure

Models of the die set and cylindrical billet were created using SOLID EDGE software package. Contact elements were constructed on all exterior surfaces of the billet, except for the bottom surface and all inner surfaces of the top die. These contact elements were constructed between the die and billet surfaces to prevent the penetration. These elements were modeled by using solid edge software and were converted into STL and STP (STEP) files. Contact elements were on the inside surfaces of the die and utilized the bottom nodes of the die. The die set was modeled with rigid material properties and the billet was modeled with an elasto-plastic material (Aluminium 6061) properties. The front and rear surfaces of die were not explicitly modeled, but were simulated by boundary conditions. Nodes on the front of billet were constrained from moving past the plane of the front portion of upper die, thus representing the front closure. The constraints were incorporated which acts similarly to a contact surface.

The coefficient of friction between the wall-billet interface and the other contact surfaces was kept constant. The planes of symmetry were simulated by using nodal restraints which did not allow the nodes to move across. The volume of the cavity of die had the same volume as that of the billet, the aim being that when the die was completely closed, the billet material would completely fill the die cavity. The top die was pushed downwards over the billet with a constant imposed velocity by hydraulic ram actuated press, while the bottom die was kept stationary. The magnitude of velocity was chosen in such a way that the computer run time of the analysis for this model got drastically reduced. The billet was positioned relative to the die cavity as shown in Fig 5 in such a manner that it allows flow of the billet material within the die cavity in all three directions. This produced a three dimensional flow pattern. The material flow simulation of the billet material carried out in Deform 3D software was studied as it filled the die and the results were obtained. The material model for the billet was that of an isotropic elasto-plastic material (Aluminium 6061) with a bilinear stress-strain curve. This model incorporates isotropic hardening where the cylindrical yield surface expands as the material yields.

The young's modulus, yield stress, and the hardening modulus were specified. The stress calculated by the deform software made use of the following equation (1).

$$\sigma = \sigma_y + E_p \times \epsilon_p \tag{1}$$

Where

$\sigma$  represents the effective stress,

$\sigma_y$  represents the yield stress of the material,

$\epsilon_p$  represents the plastic strain,

$E_p$ , the plastic modulus is defined as:

$$E_p = E \cdot E_h / (E - E_h)$$

Where  $E_h$  is the hardening modulus.

The value of the friction coefficient between the die and billet surface was maintained as a constant, and considered explicitly at locations where a contact surface of the die touched the contact surface of the billet.

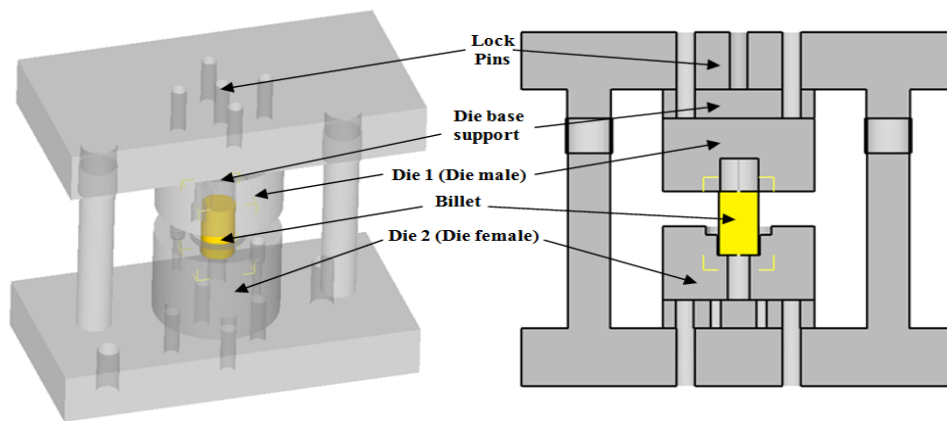


Fig 5 Initial setup of the billet in the die cavity between die halves

### III. RESULTS AND DISCUSSION

Flow simulation of the precision forging process carried out has henceforth provided critical results which gives a detailed description of the effective stress, effective strain, principal stress, principal strain, velocity and damage analysis of the component as well as die set used in the process. The effect of stress accumulation, strain distribution, material flow velocity, damage can be clearly visualized and henceforth it can be critically analyzed from the Fig 6, Fig 7, Fig 8, Fig 9, Fig 10 and Fig 11 respectively. The careful observation of the results suggest that the effective stress, effective strain, principal stress, principal strain, velocity and damage are maximum at locations where flange opens out and rib growth begins across the geometrical interlocking between the two halves of die-set and the component surface.

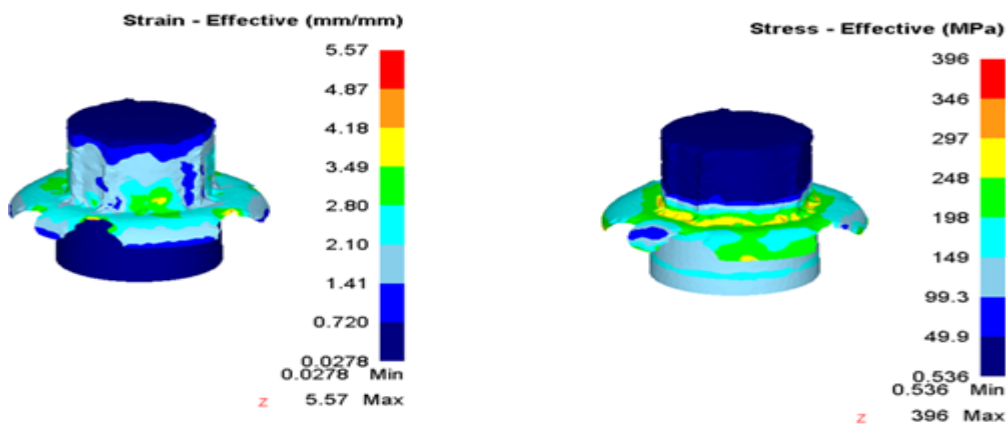


Fig 6 Effective Stress and strain distribution

Fig 6 shows the effective stress and strain distribution along various cross sections of the component, the effective stress varies from a minimum of 0.536 MPa to a maximum of 396 MPa and the effective strain varies from a minimum of 0.0278 to 5.57 mm/mm.

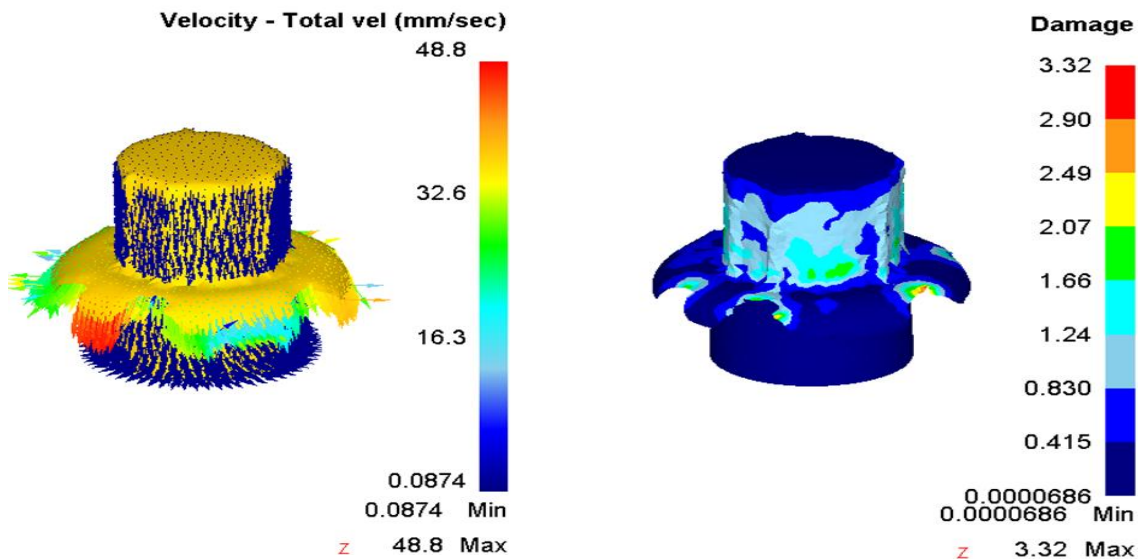


Fig 7 Velocity and Damage analysis

Fig 7 gives a brief outline of the velocity and damage analysis for the component, the velocity of flow of material during plastic deformation of the component varies from a minimum of 0.0874 mm/sec to a maximum of 48.8 mm/sec and the damage caused in the component varies from a minimum of 0.0000686 to a maximum of 3.32.

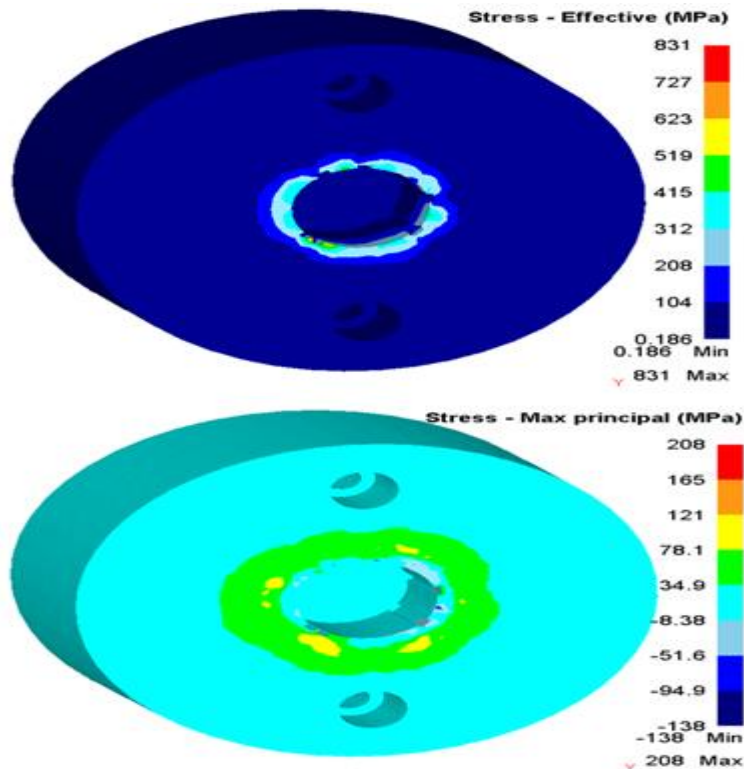
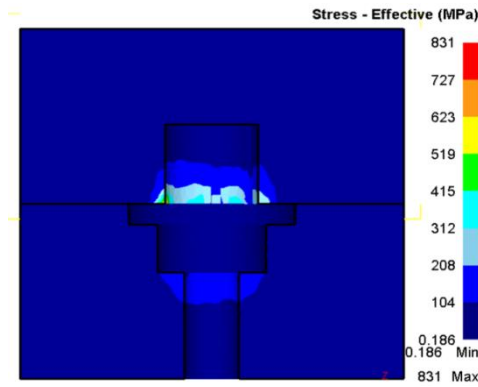


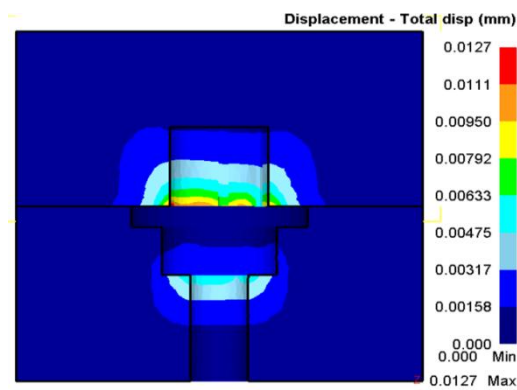
Fig 8 Effective and principal stress variations across the Die-1 cross section

Fig 8 shows the effective and principal stress distribution along various cross sections of Die-1 with a minimum Effective stress value of 0.186 MPa, maximum effective stress value of 831 MPa, and the principal stress value ranging from a minimum of -138 MPa to a maximum of 208 MPa.



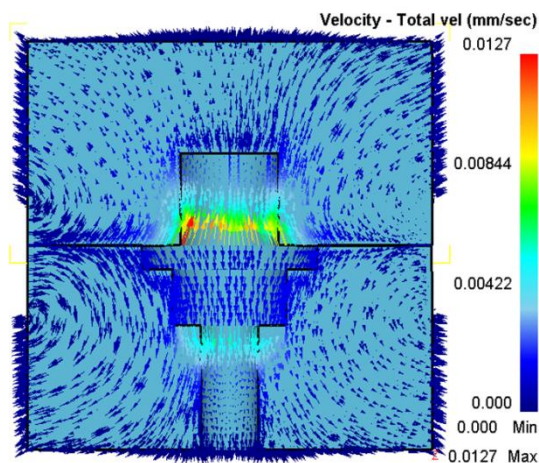
**Fig 9 Effective-Stress Analysis of Die assembly in MPa**

Fig 9 shows the effective stress distribution along various cross sections of Die assembly with a minimum value of 0.186 MPa and a maximum value of 831 MPa.



**Fig 10 Displacement analysis of die-component setup in mm**

Fig 10 shows the displacement analysis for the die-component setup, the displacement for the die-component setup varies from a minimum of 0 mm to a maximum of 0.0127 mm.



**Fig 11 Velocity analysis of die-component setup in mm/sec**

Fig 11 shows the velocity analysis for the die-component set-up, the velocity of flow of material during plastic deformation of the component in the die setup varies from a minimum of 0.000 mm/sec to a maximum of 0.0127 mm/sec.

#### IV. CONCLUSION

- [1] The effective stress on the component decreases as the initial temperature of the billet increases.
- [2] The maximum effective stress occurs during the initial contact of the lower and the upper die with the work piece.
- [3] The maximum effective stress is found to be lesser on the component if open upsetting is carried out on billet before final forging stage.
- [4] The stress concentration is maximum at the contact surface of parting lines of two halves of die set and the flange portion of the component.
- [5] It is observed that presence of small ribs on the outer cylindrical surface restricts the free flow of metal in the small recess of die cavity during forging, which leads to surface cracks, improper and incomplete rib formation.
- [6] The critical evaluation of the results of the investigation carried out suggests that the problems faced in precision forging of the component can be overcome by:
  - Increasing the height of the billet, upsetting the billet and then carrying out the press forging.
  - Providing suitable fillets in the die-set.
  - Ensuring suitable gap between the two die halves when the tool and die setup is pressed.
  - Increasing the dimensions of ribs or eliminating the need for ribs in the component.
- [7] It has also been found that the Aluminium 6061 connector can be press forged (by precision forging) with maximum benefits if the critical conclusions drawn from the analysis are successfully incorporated in the process.

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