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Numerical Analysis of Cold Forging Effect on Mechanical Properties of Al/Sic Metal Matrix Composites

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Abstract:*The objective of this work was to investigate the effect of cold forging on mechanical properties and microstructural study of Al MMCs, at different wt% of SiC and forging cycle. The Al-SiC composite material was fabricated by stir casting method at different weight percentage of SiC such as 4% and 6%. Further, the deformation characteristics during open-die forging of Al-SiC composite at cold conditions were investigated. Cast and forged composite material was subjected to hardness test, tensile test and impact test. The grain size, microstructure behavior was investigated using optical microscope and SEM. The FEA method was used to evaluate various characteristic properties such as effective stress, strain, velocity, damage, total load in DEFORM-3D. Results showed that due to forging cycle the grain size was reduced by 30% to 35% from initial size. In FEA analysis results show that maximum effective stress, velocity, damage and decrease in strain is presented were high at 60% of forging cycle and 6 % SiC.*

Keywords: *Mechanical properties, Composites, Al/SiC, Simulation*

I. Introduction

After completing the experimentation, the numerical process starts. As specified here DEFORM-3D software to do finite element analysis to find the Forging Properties of material [1]. This tool has a material library with the properties and allow user to change as per the requirement. By designing the geometry, basic part geometry is available in DEFORM software using the Lagrangianformulation[2].From above literature review [3-6]. It is clearly that the most of researchers has working or concentrated on the studying extruded and rolling behaviour of aluminium based composites. Whereas comparatively few researchers are studied on the effect of the forging operation on the aluminium based MMCs composite[7-10].

The aim of this study is to estimate the effect of cold forging on mechanical properties like hardness, impact strength and tensile properties at room temperature and microstructural of a whiskers reinforced of Al MMCs, which contains of an Al6061 matrix phase and reinforced with 10 % wt, 15 % wt.of SiC particles.

II. Finite Element Analysis

Deform 2D/3D pre-processor consists of few steps such as general, geometry, Meshing, movement, simulation control, inter object and data. In this tab object can be defined such as top die, bottom die and work piece.Top and Bottom dies, consider as a rigidtype of object and the work piece is plastic type of object. Defining the plastic properties of Al-SiC composite material in material library can be loaded in a DEFORM material database and choose Al6061-T6 COLD + SiC.

The engineering stress and strain data were calculated from the corresponding recorded data from forging experimental values. The stress strain curve of type $\sigma = a\varepsilon^b$MPa for Al alloy composite is uploaded in the material library of DEFORM software further FEM analysis. This tab is used for importing the CAD model and some basic models can be created on the geo primitive tab shown in Fig. 1. The behaviour of plastic material of the object is defined by a flow stress function or flow stress data of a material.Fig. 2 show the mesh formation is an important aspect in finite element analysis, as the mesh is divided the total area into small parts which is solved individually and then integrated to get the result. Based on the type of meshing accuracy of the problem will be increased. The meshing is performed by using tetrahedral elements, and fine mesh generated near to the outer side of edges.Considering size ratio of element to performing better scope of the forging operation.

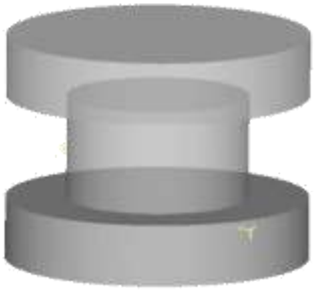


Fig. 1 CAD Model

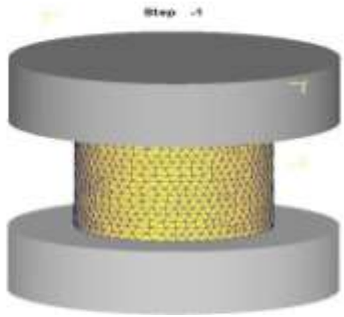


Fig. 2 Meshing Model

This tool is used for the given initial condition of the forging operation. Based upon our instrument we can select hydraulic press machine of constant ram speed 1 mm/Sec shown in Fig. 2. This is very important steps in preprocessor. It defines types of simulation,

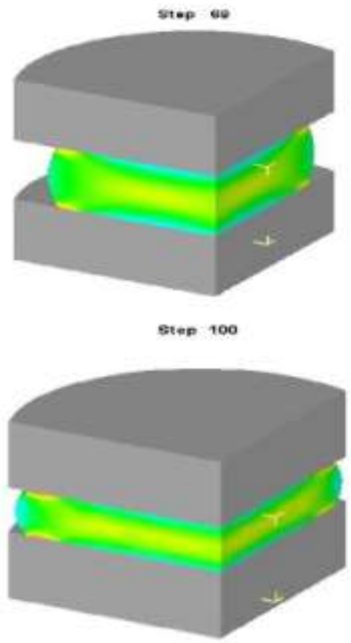


Fig. 3 Forged condition

(a) 40% Deformation
(b) 60% Deformation

simulation mode, simulation steps, step increment andre-mesh criteria. For cold isothermal forging we selected Lagrangain incremental types of simulation and deformation mode should be turned on and heat transfer mode should be turned off. In step increment command initial step is -1 and select no.of step is 100 by increment of step is 1.The next step is selection of stroke per step and selected as Pri die displacement at constant 0.3 mm/step after all steps over then press ok button.This tab shows the relation between die and work pieces. Here selected work piece as a slave to both the die. For good lubrication select cold forming process and a friction.Considering the 0.0634 mm interference tolerance between the work-piece and both the die. Smaller interference tolerance used for the very small job to prevent the excessive overlap between the die and the work-piece. Select default value of tolerance and press generate all. After completing all the above steps go to the last step of pre-processor is Database Generation. Click on the tab and check the data. They show all steps in pre-processor is correct or wrong, if there are any yellow or red flags, resolution them, once again generate the database. Then solution is done and exit the pre-processor and start the simulation.

Next step is simulation. It is started by clicking the run tab. This is evaluated a series of operations and whenever new mesh is required they can generate it. A simulation is stopped by clicking the stop or in the

Fig. 4 Variation of damage in actual

header.The simulation is stopped after the all iteration is over. If a simulation does not satisfy the convergence criteria within the limit, they start once again for new simulation and do all steps. After simulation over the next step is post processor. It is used to analysis and extract data from the simulation results in the database file. All results steps which were saved by the simulation engine are available in the post-processor. The complete forging process simulation is performed in 100 steps and movement of die in each step is equal to 0.3 seconds. A Deform-2D/3D post processor consist with a different variety of features allow to check the results of CAD model and they presented in a such way that to result are easily understood and a efficient manner.Figure 3 shows the composite material in different degrees of deformation. For 40% and 60% deformation maximum steps required for forging is 69 and 100 steps respectively. All results calculated in post-processor is discussed in next chapter.

III. Results And Discussion

3.1 FEA analysis of cold forging experiments

In this section, we have discus about the forging analysis of Al6061/SiC composite. Cold forging operations done on the hand operated compressive machine and the values of Al alloy and Al-SiC composite are very similar. By uploading three different flow stress vs strain curve of Al-SiC at

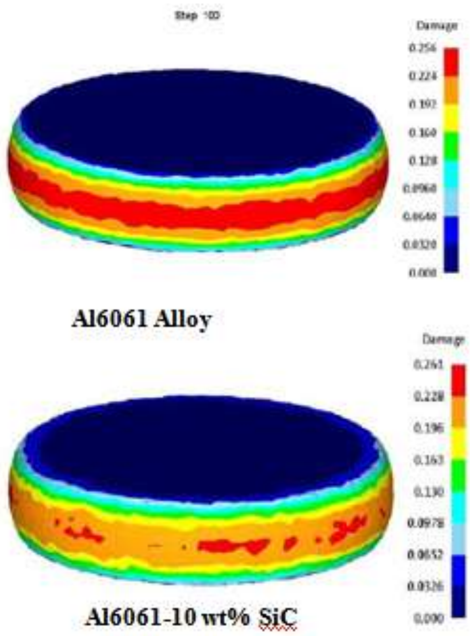


Fig. 5 Variation of damage in Deform-3d

of the billet shown in the Fig. 5 Point 1 and 3 is the top and bottom position of billet respectively and point 2 is middle of the billet.Fig. 5 shows the maximum damage is middle of billet height and point 1 and point 3 shows the small damages are generated its 0.0341 at the 30mm of reduction of height. Point 2 shows the 0.24 damage at the 30mm of reduction of height

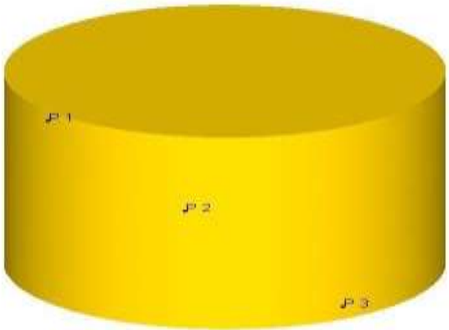


Fig. 6 Points tacking on the billet

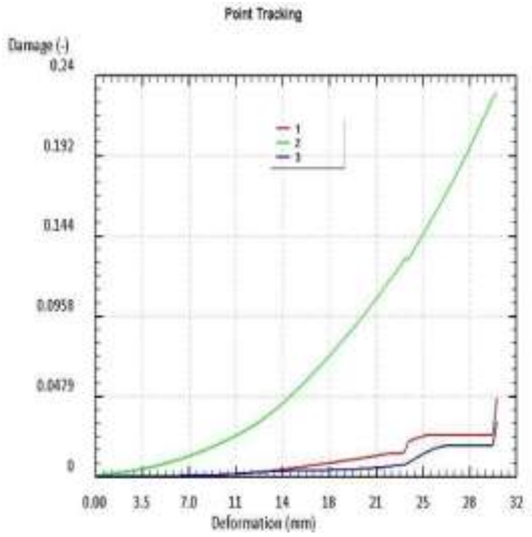
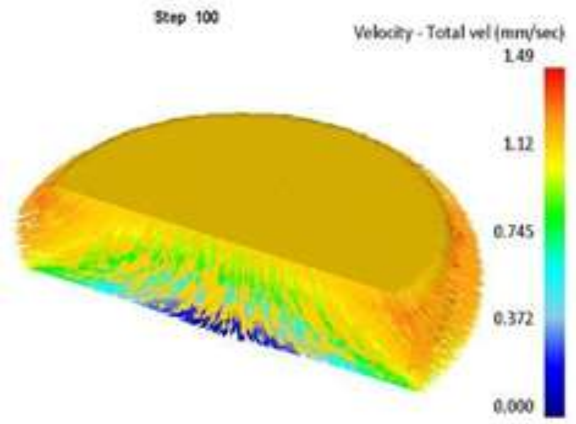


Fig. 7 Variation of damage vs. deformation along the point tracking

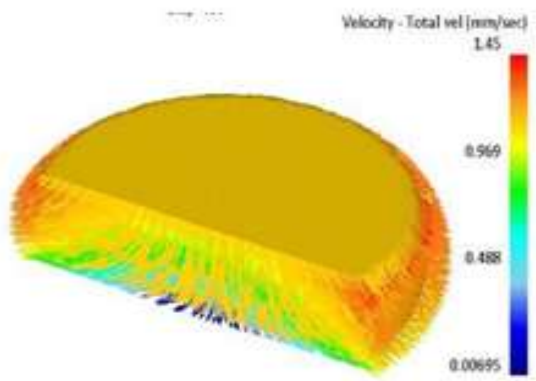
Different weight percentage in the material library and analysis by three different forging stage as 20%, 40% and 60% reduction.It was also observed that cracks are initiated only after compression of the billets by an amount of 40% - 50% depending on the weight percentage of the SiC particles. The specimens distorted completely by the reduction of 70% to 80% along the height. Fig. 4 shows the variation of damage generation along the billet height and diameter. Maximum damage is available at the middle of height, of the billet and depends upon the steps or stroke. Here the damage in Al6061 alloy is 0.256 and 0.261 in 10 wt% SiC composite. The % of SiC in Al matrix is very less and its not affected on the damage.Fig. 4 shows the damage on actual condition. The damage is available only outer surface of the billet. There is no crack present inner region of the billet. Before initialization of the crack some of the aluminium and silicon carbide particle are coming out of the surface. Further applying the load crack will propagate at a certain length.For behaviour of the damage with respect to the deformation, we have select three point on the surface

3.2 Effective Velocity

In cold forging, compressive load acting on the billet the material particle moves towards the nearest surface boundary shown in Fig. 6. It can be observed that the velocity of the particle depends upon the deformation load and particle position in the billet. The outer regions perform are higher velocity as compared to the inner regions, which is close agreement with the composite interfacial friction law considered. Red colour shows the maximum velocity particle which each nearest to the outer surface and blue colour shows the minimum velocity particle.which present middle of the surface. By increasing the SiC percentage in the Al matrix velocity of particle is slightly reduced.Fig. 7 shows variation of velocity along the point tracking, maximum velocity is present on the outer surface and its top of the deformation height. Velocity inside the billet is very less because the middle particle consists of high cohesive bond between the two atoms. Further point 2 and 3 velocity decreases from the top to bottom.Maximum velocity at top, intermediate velocity at middle and minimum velocity at bottom.the variation of effective stress on the billet along the deformation height and diameter.



(a) Al6061 Alloy



(b) Al6061- 10wt% SiC

Fig 8 Velocity along the deformation-Deform 3D

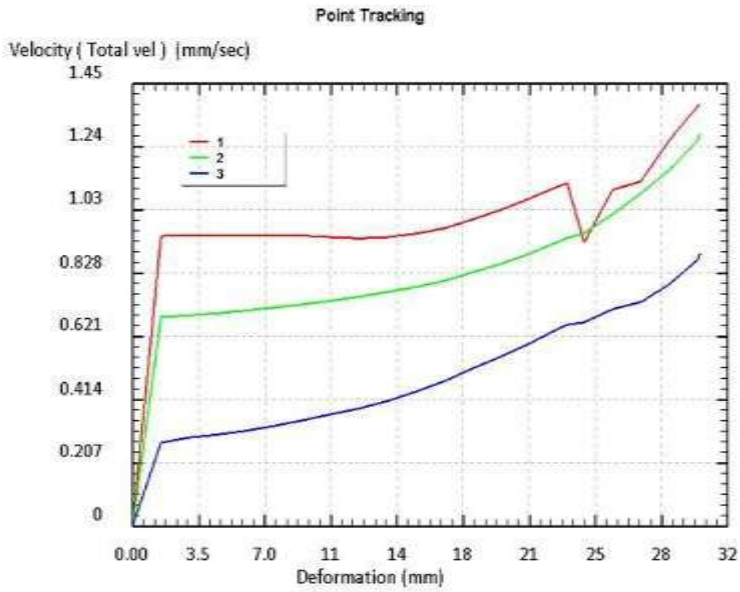
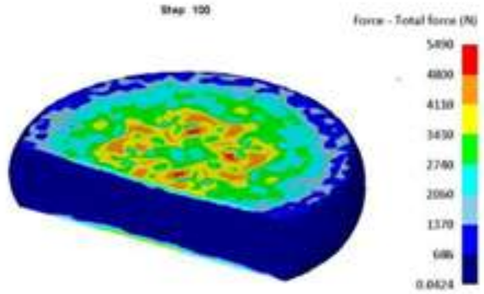
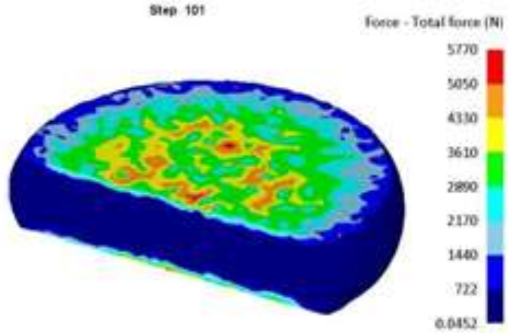


Fig 9 Variation of total force along the deformation –Deform 3D

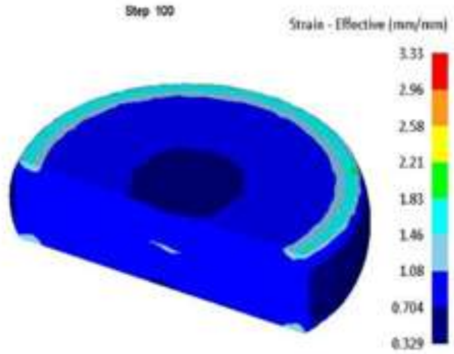


(a) Al6061 Alloy

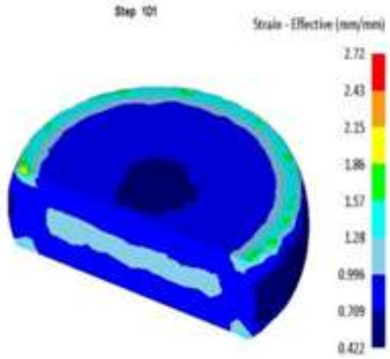


(b) Al6061-10wt% SiC

Fig 10 Variation of total force along the deformation –Deform 3D



(a) Al6061 Alloy



(b) Al6061-10wt% SiC

Fig. 11 Variation of effective strain along the deformation- Deform 3D

It is clearly evident that magnitudes of effective stresses are higher in Al-10wt% SiC as compared to Al alloy corresponding regions and magnitude is 273 Mpa and 247 MPa respectively. Maximum stress present in outer edge side of the billet and minimum stress is the center region of the billet. Effective stress is increasing along with the diameter of the billet.

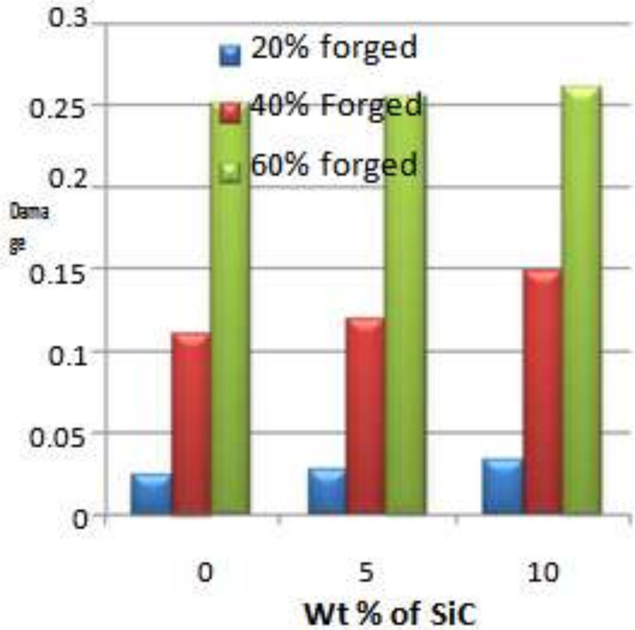


Fig 12 Comparison of forging effect and wt% of SiC on the damage of Al-SiC MMCs

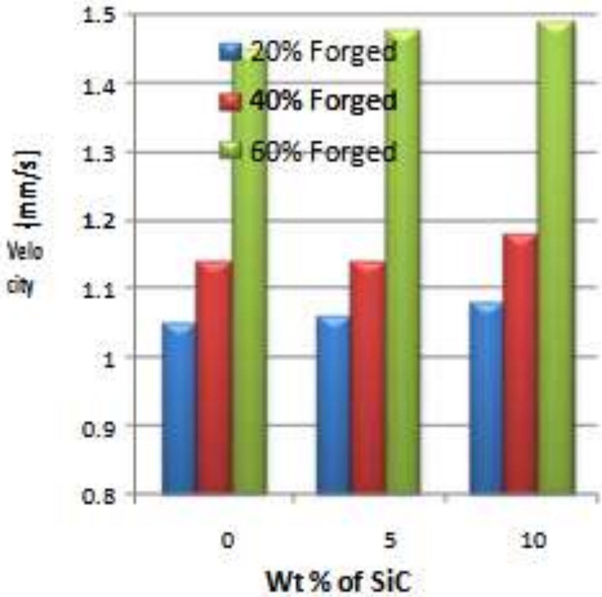


Fig 13 Comparison of forging effect and wt% of SiC on the damage of Al-SiC MMCs

2.3 Effective Stress and Strain

Figure 9 shows the variation of effective strain along the deformation and diametrical direction. Maximum strain is present on the surface edges of the billet and minimum is the central region of the billet, because of the maximum displacement of the particle is present towards the outer surface, and displacement of middle particle is very small. It can be seen that the major portion is subjected to strain in the order 0.7 to 0.9 magnitudes, except at the edges. Strain is higher in Al6061 alloy as compared to the Al-10wt%SiC,which indicates that the ductility decreases with the increase in the percentage of SiC.Also, the strains in the central region of pre-form are low and eventually almost zero at the centermost regions near to the upper and bottom flat surfaces. This confirms the presence of sticking friction zone at that region.

2.5 Total load

Figure 10 shows the variation of total force on the billet along the deformed diameter. It is clearly evident that magnitudes of total force is higher in Al-10wt% SiC as compared to Al alloy corresponding regions and magnitude is 5490N and 5770N respectively. Maximum total force present in inner surface of the billet and minimum force is the middle of the billet. Total force is decreasing along the diameter of the billet. The average total force in both material Al alloy and Al6061-10wt% SiC are around 2000N to 3000N.

2.6 Comparative Study

Graph plots are drawn based on the results obtained from Deform-3D, which gives a better idea of variation of damage, velocity, stress and strain along with the change in weight percentage of SiC in aluminium. The Al-SiC composition at different weight percentage as 0%, 4% and 6% are plotted below.

a) Damage

Figure 10 shows the comparison of forging effect and percentage weight of SiC on the damage of Al-SiC composite. It is observed that increasing the forging cycle leads to the drasticaly increase in damage or crack of Al alloy and Al–SiC composites. However, when compared with forging cycle on Al alloy and Al–SiC composites shows significant result in the damage. The maximum damage values of Al6061, Al–5 wt% SiC and Al–6 wt% SiC composites are 0.256, 0.258 and 0.261respectively at 60% forged condition. A damage increased by 342.1%, and 681.43% for has been observed in as 40% and 60% forged cycle of Al–6% wt SiC composites respectively when compared with their 20% forging cycle. By adding of 4% wt and 6% wt SiC in to the Al6061 matrix, damage increased by the 0.78% and 1.9% respectively at the 60% forged cycle. This result shows that addition of SiC lead to slightly increasing in damage in Al-SiC composite material.

b) Effective velocity

Fig.11 shows the comparison of forging effect and wt% of SiC on the effective velocity of Al-SiC composite.It is observed that increasing the forging cycle leads to the drasticaly increase in effective velocity of material. The maximum effective velocity of Al6061, Al–5wt% SiC and Al–10wt% SiCcomposites are 1.45 mm/s, 1.48 mm/s and 1.49 mm/s respectively at 60% forged condition. An effective velocity increased by 9.2% and 37.9% for has been observed in as 40% and 60% forged cycle of Al– 10wt% SiC composites respectively when compared with their 20% forging cycle. By adding of 5 wt% SiC and 6 wt% SiC in to the Al6061 matrix, effective velocity increased by the 2.06% and 2.7% respectively at the 60% forged cycle. This is shows that additions of SiC lead to slightly increasing in damage in Al-SiC composite material.

c) Effective Stress

Fig. 12 shows the comparison of forging effect and wt% of SiC on the effective stress of Al-SiC composite.It is observed that increasing the forging cycle leads to the increase the effective stress of Al–SiC composites. The effective stress at 60% forged condition of Al, Al–5wt% SiC and

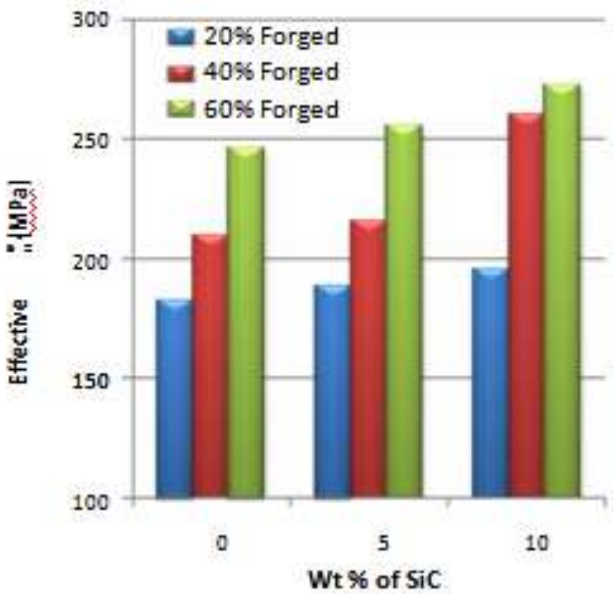


Fig. 12 Comparison of forging effect and wt % of SiC on the effective stress of Al-SiC

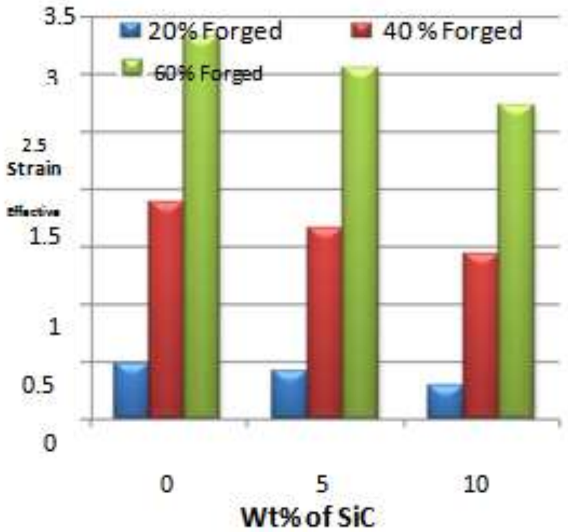


Fig. 13 Comparison of forging effect and wt% of SiC on the Effective Strain of Al-SiC

Al–10wt% SiC composites are 247 Mpa, 256 Mpa and 273 Mpa respectively. A effective stressincreased by 39.28%, and 33.16% for has been observed in as 40% and 60% forged cycle of Al– 10wt% SiC composites respectively when compared with their 20% forging cycle. By adding of 5 wt% SiC and 10 wt% SiC in to the Al6061 matrix, strain reduced by 8.4% and 18.3% respectively at the 60% forged cycle.

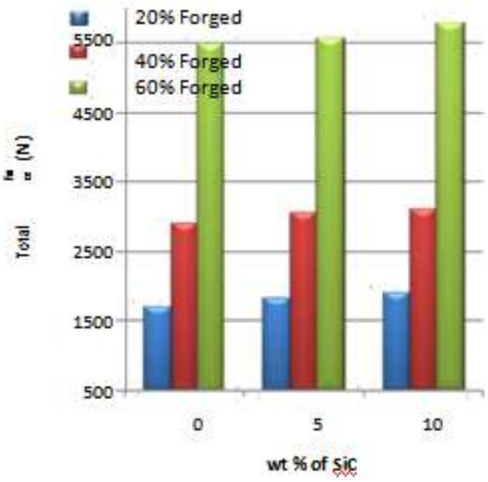


Fig 14 Comparison of forging effect and wt% of SiC on the total force of Al-SiC composite

d) Effective strain

Fig.13 shows the comparison of forging effect and wt% of SiC on the effective strain of Al-SiC composite.It is observed that increasing the forging cycle leads to the slightly reduction in strain of Al– SiC composites.. The effective strain at 60% forged cycle of Al6061, Al–5wt% SiC and Al–10wt% SiC composites are 3.33, 3.03 and 2.73 respectively. A effective strain increased by 394.8%, and 841.1% for has been observed in as 40% and 60% forged cycle of Al–10wt% SiC composites respectively when compared with their 20% forging cycle. By adding of 5 wt% and 10 wt% SiC in to the Al6061 matrix, effective strain reduced by the 8.4% and 18.3% respectively at the 60% forge cycle.

e) Total force

Fig.14 shows the comparison of forging effect and wt% of SiC on the total force of Al-SiC composite.It is observed that increasing the forging cycle leads to the drasticaly increase in force of Al6061–SiC composites. The total force at 60% forged condition of Al6061, Al–5wt% SiC and Al–10wt% SiC composites are 5490N, 5560N and 5770N respectively. Total forcee increased by 63.1%, and 203.6% for has been observed in as 40% and 60% forged cycle of Al–10wt% SiC composites respectively when compared with their 20% forging cycle. By adding of 5 wt% SiC and 10 wt% SiC in to the Al6061 matrix, force increased by the 1.2% and 1.1% respectively at the 60% forge cycle.

IV. Conclusions

Conclusions In the present work, the stair casting method is used for making Al-SiC composite. Then cold forging of an Al6061/wt% SiC composite was tested at room temperature (25). The flow stress-strain curve is obtained from the cold forging experiment. That stress strain curve data are uploded in the Deform-3D software to FEA analysis. After forging process over next test is the evaluation of mechanical properties such as hardness, tensile and toughness of the casted and forged Al-SiC MMCs material, further to study the microstructure characterisation of Al-SiC material by using optical and SEM techniques. By using the Deform-3D FE tool to analysis of cold forging of a Al-SiC composite was performed in order to evaluate the damage, velocity and effective stress-strain distributions in different points of the trial. Al-SiC with 10% SiC reinforcement possess higher effective stress formation in all 12 cases studied with value of 273 MPa in DEFORM. Finite element analysis of the deformation behavior of the composite can be carried out as that for a homogeneous material. Total energy requirements during open-die forging of aluminium composite having higher SiC are found to be higher due to the higher strength of the material. Analysis of open-die forging of Al-SiC composite was performed using DEFORM-3D and the distribution of effective stress, effective strain, effective strain rate, and velocity vector profile was generated. Higher Magnitudes of effective stress, and strain were found at the corners and edges of the billet. This was also confirmed by the presence of severe cracks at those regions during the present experimental investigations.

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