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# Finite Element Analysis and Experimental Study on the Effect of Extrusion Ratio during Hot Extrusion Process of Aluminium Matrix Composites

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**ABSTRACT**

The finite element (FE) analysis on the effect of extrusion process parameter namely, extrusion ratio at different billet temperatures on the plastic strain and strain rate of aluminium matrix composite during hot extrusion process has been dealt. The dynamic explicit FE code in ANSYS 15.0 workbench was used for simulation. The FE analysis was carried out on the SiC reinforced aluminium matrix composites for three extrusion ratios 4:1, 8:1 and 15:1, for the billet temperatures in the range 350 °C - 450 °C in steps of 50 °C. The plastic strain and strain rate were found to increase with increase in the extrusion ratio. A minimum strain and strain rate was found to occur at the billet temperature of 450 °C. The silicon carbide particles reinforced aluminium matrix composites were then extruded at the optimised temperature of 450 °C for various extrusion ratios as mentioned above. The effect of extrusion ratio on the microstructure and surface quality of extruded rod was studied.

**Keywords:** Aluminium matrix Composite; Finite element analysis; Extrusion ratio; Plastic strain; Strain rate

## 1. INTRODUCTION

Aluminium matrix composites (AMC) are synergic materials having high specific strength, high specific modulus, high wear resistance and improved high temperature properties[1-2]. They are the potential materials to replace metals and alloys in weight critical applications. However, these exotic materials are not being seriously considered as suitable materials for automotive components. This is due to the inherent problems in castings like porosity, segregation, etc. associated with primary processing used for composite preparation. This could be overcome by secondary processing techniques namely extrusion, forging, rolling, etc. The enhancement of properties of the secondary processed composites is due to recrystallisation, removal of porosities, control of material flow, etc. The quality of AMC extrusion depends on the factors such as extrusion speed, extrusion ratio, billet temperature, shape of extrusion die, die-billet friction and so on. Extrusion, though an important metal working technology, has not been predominantly used for engineering components[3]. This is due to the requirement of relatively high and sustained extrusion pressures, availability of limited data on the flow behaviour of billet at different extrusion ratios and billet temperatures. Prediction of extrusion pressure/load and optimisation of extrusion process parameters namely ram speed, extrusion temperature, extrusion ratio, die design, etc. play a significant role in production of components using extrusion process.

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The application of the finite element method in the extrusion industry is to identify the process parameters and to act as a bridge between the experimental study and the actual extrusion. The applications of FEM for the extrusion process are to predict the load, temperature, material flow pattern, surface quality, etc.[4-6]. So far, only limited study has been made in the modelling and analysis of aluminium composite extrusion using FEM and reported by the various researchers. Zhao[7]*, et al.* analysed the condition of temperature field, velocity field, stress and strain field during extrusion using HyperXtrude software. They predicted the possible defects in practical extrusion. Charpentier[8]*, et al.* studied the characteristics and modelling of high temperature flow behaviour of aluminium alloy 2024 and explained the effect of deformation condition on their microstructure. Hambli and Badie[9] studied the material damage during extrusion using ABAQUS FE model. They found that the maximum damage was at the material/die interface, in particular, at the surface of the work piece and were in agreement with the experimental observations which show that defects are often present at the surface. The simulation results also indicated that the equivalent plastic strain is a potential cause for material damage as it is related to material distortion and hence possible for damage[10]. Berski[11], *et al*. used FORGE 2 to analyse the extrusion of Al/Cu bimetallic rod in single and double reduction dies and found that the double reduction die was preferable with an optimal extrusion ratio of 2.

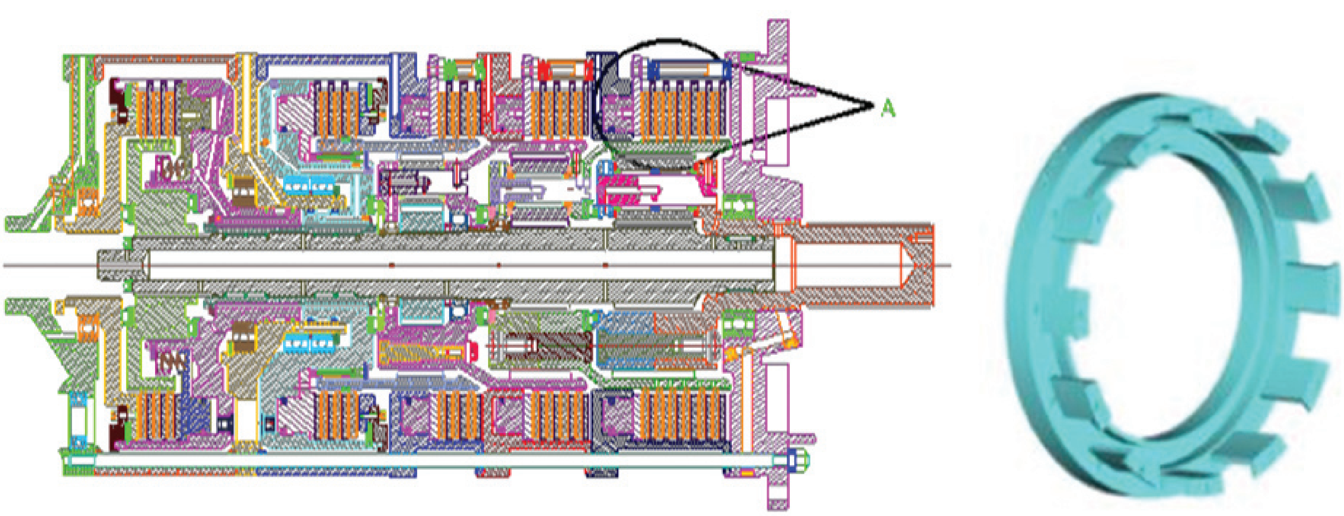
Few experimental investigations to optimise extrusion parameters are also available. Luan[12], *et al.* attempted to optimize the extrusion parameters of Al2O3p reinforced Al2024 and Al6061 aluminium alloys produced by squeeze casting method. They optimised higher extrusion temperature of 500 °C - 560 °C based on the reproducible tensile properties, owing to better ductility of matrix alloys and smaller size (0.15µm - 0.3 µm) of the reinforcement particles. The effect of extrusion rate (5 mm/s, 7.5 mm/s, 10 mm/s) on the mechanical properties was found insignificant. It was found that increasing the extrusion ratio above 10:1 resulted in a decrease in strength and an increase in elongation. Chanda[13], *et al.* analysed the heat transfer conditions to demonstrate the conditions under which the deforming materials becomes vulnerable to hot shortness. They concluded that hot shortness occurs when the reduction ratio is high. The significant difference in the shear flow of aluminium compared to other metals is that the centre of aluminium billet is extruded first and the peripheral part flows later causing more severe deformation on the surface.

The objective of the present study is to analyse the effect of extrusion ratio and billet temperature on the strain (deformation) and the strain rate (deformation rate) during the hot extrusion behaviour of Silicon Carbide (SiC) reinforced Al2014 composite, which was analysed with three different extrusion ratios 4:1, 8:1, and 15:1 for billet temperatures in the range 350 °C to 450 °C in steps of 50 °C. The strain and strain rate during metal working have an important influence on the flow stress and in turn the flow behaviour. The flow behaviour affects the quality and the properties of the extruded parts. The results of the study will help in predicting the flow stress required for the deformation during extrusion. Experimental study was also carried out on Al2014-10 wt.% SiC composites at extrusion ratios 4:1, 8:1, and 15:1 for the billet temperature of 450 °C, which was optimised from FE analysis, based on occurrence of the lowest plastic strain and strain rate.

## 2. RESEARCH BACKGROUND

As space and weight limits continue to increase the importance in the design of armoured fighting vehicles (AFVs), the need to utilize new processes, technologies and materials, is required. Research into the development of light weight transmissions in view of increased mobility of these vehicles, necessitated the search of low density materials with properties equivalent to that of high density materials. The automatic transmission for AFV designed and developed by Combat Vehicles Research and Development Establishment (CVRDE), Chennai, is a fully automatic transmission with four speed forward and two speed reverse gears. The static and dynamic clutch housings which are presently made of cast iron and steel respectively, contribute around 30% of total weight of the gearbox. In the continuing effort to provide a light weight automatic transmission, it is proposed to replace the existing clutch housing with light weight equivalent. The cross section of the gearbox of AFV transmission is shown in Fig. 1. The detail 'A' shows the static clutch housing. A clutch pack consisting of alternate friction plates and pressure plates are stacked in the clutch housing. During engagement and disengagement of the particular gear, the annulus of the corresponding planetary is braked by means of hydraulic multi-plate clutches against these static clutch housings. The static clutch housing is therefore required to possess adequate strength, rigidity and high wear resistance. The static clutch housings are at present made of cast iron to IS 210 Grade 35 material. Selection of appropriate material and process to suit the above requirement is very important.

Based on the detailed study of clutch housing used in various high power transmissions available worldwide, aluminium alloy with increased wear resistance is found suitable for the above application. Considering the requirement of higher strength equivalent to cast iron and higher wear resistance, heat treatable wrought aluminium alloy based composites are selected for this application. In this study, aluminium alloy composite i.e., Al2014 (HE 15) reinforced with 10 wt.% SiC particle is used. Al2014 HE15 is an extruded grade aluminium alloy and data on extrusion of the above composite is not available. Hence, study on the effect of extrusion process parameters of this composite is inescapable. In the present study, both the FEM simulation and the experimental study are carried on the sample level the results of which may be used for the actual component development in future.




(a) (b)

**Figure 1. (a) Gear box of AFV transmission and (b) 3D model- static clutch housing.**

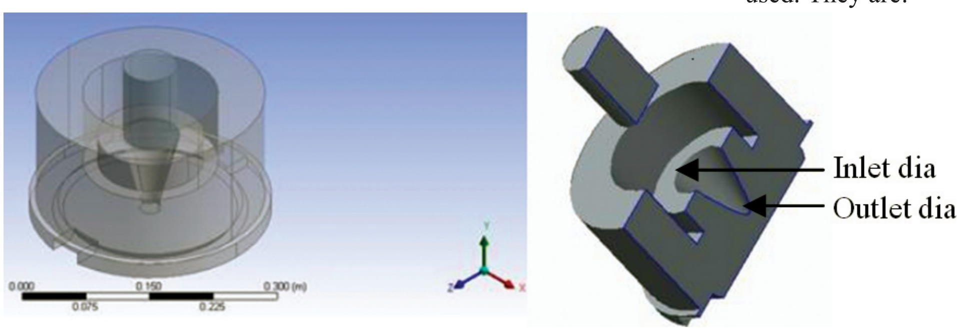
## 3. MATERIALS AND INPUT PARAMETERS

The billet and die materials used in the present study are Al2014-SiC composite and D2 die steel respectively. The properties of the billet and die material used as input parameters in the present simulation are given in Table 1. The material properties of the composite used for the analysis were determined from the tensile tests. The billet was of 64 mm in diameter and 100 mm in height.

**Table 1. Properties of billet and material**

| Properties | Billet (Al-SiC) | Die (D2 steel) |
|---|---|---|
| Density (g/cm$^3$) | 2.8 | 7.695 |
| Elastic modulus (GPa) | 73 | 207 |
| Poisson's ratio | 0.3 | 0.33 |
| Coefficient of thermal expansion | 23 x $10^{-6}$ | 10.3 x $10^{-6}$ |

Three-dimensional (3D) finite element analysis was carried out as a macroscale model wherein the material was considered as rigid visco-plastic, homogeneous and isotropic. Coulomb friction condition was assumed between die-billet assembly. A friction coefficient of 0.1 was assumed between die-material interface. The 3D model of die container is as shown in Fig. 2.




(a) (b)

**Figure 2. (a) 3D model and (b) Cut section of die-billet assembly.**

The die assembly consists of three parts namely the base plate, the die container with replaceable die insert and the upper plate. In the present study, three different extrusion ratios 4:1, 8:1, and 15:1 were used. The inlet and outlet diameters of the die insert for the three different extrusion ratios are listed in the Table 2.

The extrusion analyses were carried out with the billet temperatures ranging from 350 °C to 450 °C in steps of 50 °C. A typical case of thermo-mechanical analysis was performed wherein the billet heat and the die-billet friction heat is assumed to dissipate through the die surfaces. The part modelling was done using Creo 2.0 software. The FE mesh was generated automatically for the space domain including the billet and the die. Finer mesh was given to billet and die faces which were in contact with billet as shown in Fig. 3.

**Table 2. Dimensions of die insert for different extrusion ratios**

| Extrusion ratio | 4:1 | 8:1 | 15:1 |
|---|---|---|---|
| Inlet diameter, D (mm) | 64 | 64 | 64 |
| Outlet diameter, d (mm) | 32 | 22.6 | 16.5 |

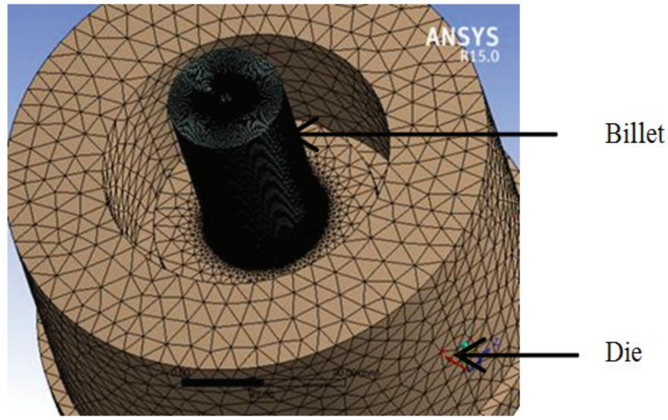



**Figure 3. Finite element meshes of die container and billet.**

Element shape of the billet and die was tetrahedral. Since, the die is fixed and used as the tool, rigid elements were given. As the billet is subjected to linear motion and used as work piece it was given with flexible elements. In this work, displacement of 500 mm as a function of velocity along Y axis in the negative direction was given as boundary condition to the billet.

In the assembly of die and billet, two constraints were used. They are:

*Constraint 1*: the die was fixed with respect to three axes i.e. x, y, and z.

*Constraint 2*: the die and billet were aligned with respect to their center axes.

The nodes on the x-axis were constrained and the displacement in terms of velocity is applied in the y-axis. Three-dimensional dynamic analysis of the composite billet was carried out for the extrusion ratios namely 4:1, 8:1, and 15:1. The ram was moved at an outflow velocity of 2 mm/s. The plastic strain and the strain rate at 350 °C were studied. Similarly, the analysis was carried out for extrusion temperatures 400 °C, 450 °C, 500 °C, and 550 °C.

## 4. MATERIAL MODEL AND STRAIN RATE CALCULATION

A dynamic explicit finite element code is generally used to perform the simulation of extrusion process[7]. In the present work, explicit dynamics module in ANSYS 15.0 workbench was used for the analysis of hot extrusion process. The software can couple the temperature application of billet by using Autodyne solver with explicit dynamics. It is used to model different modes of material behaviour.

For the FEM analysis of metal forming process, a precise knowledge of the relationship of the flow stress of the material, applied strain, strain rate and temperature of deformation is essential[14]. Accurate prediction of flow stresses is required for accurate prediction of forming load or stresses[15]. In the present work, Johnson-Cook material model as given in Eqn. (1), which has been extensively used for calculating the material response during metal forming operations, is used.

$$\sigma = [A + B(\varepsilon_p)^n][1 + C\log(\dot{\varepsilon}_p / \dot{\varepsilon}_0)][1 - T^m] \quad (1)$$

where $T^m = (T - T_r)/(T_m - T_r)$

$T_m$ is the melting point, $T_r$ is the ambient temperature, $T$ is the billet temperature, $T^m$ is the temperature exponent, $\dot{\varepsilon}_p / \dot{\varepsilon}_0$ is the plastic strain rate. *A, B, C, n,* and *m* are material constants for the Johnson-Cook strain rate dependent yield stress.

In a hot working process, at the working temperature, the material undergoes recrystallisation along with work hardening. The recrystallisation is affected by the strain rate and the billet temperature during high temperature plastic working. The strain hardening may be nullified by recrystallisation. Therefore, in hot working we may only consider the effect of temperature and strain rate on the yield strength of the material. The effect of strain rate may be written as given below in Eqn. (2).

$$\sigma_f = \sigma_0 (\dot{\varepsilon})^m \quad (2)$$

where $\sigma_f$ is the flow stress, $\dot{\varepsilon}$ is the plastic strain rate, *m* and $\sigma_0$ are material parameters. Since the effects of strain rate and strain hardening may vary at different temperatures, this presents a major problem of testing each metal and alloy at different temperatures, at different strain rates and to different extents of strain.

## 5. FEM ANALYSIS AND DISCUSSION

The finite element analysis was carried out to study the effect of extrusion process parameter namely extrusion ratio on the plastic strain and strain rate of aluminium matrix composite during hot extrusion process and the findings are discussed in the following sections. The effect of billet temperature on the plastic strain and the strain rate for various extrusion ratios are shown in Figs. 4 and 6, respectively. Contour plots of plastic strain and strain rate at extrusion ratios of 4:1, 8:1, and 15:1 at extrusion temperature of 350 °C are plotted in Figs. 5 and 7, respectively.

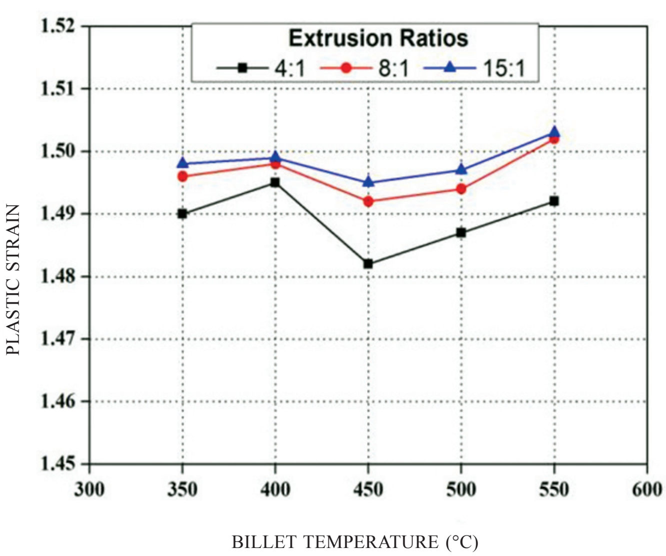



**Figure 4. Effect of extrusion ratio and billet temperature on plastic strain.**

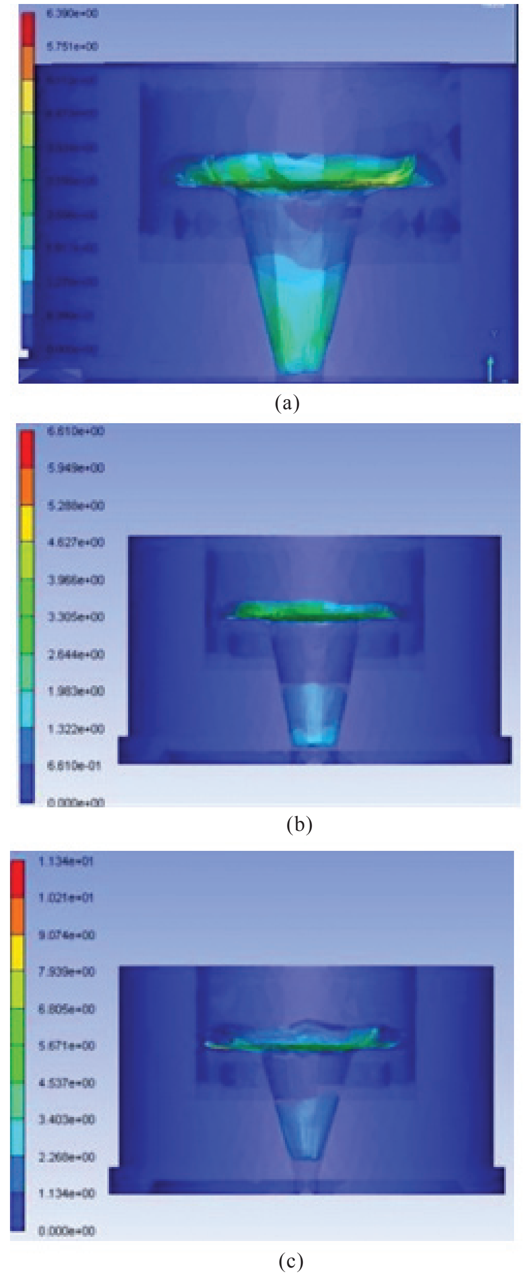



**Figure 5. Contour plots of plastic strain at extrusion temperature 350 °C: (a) Extrusion ratio 4:1, (b) Extrusion ratio 8:1, and (c) Extrusion ratio 15:1.**

### 5.1 Effect of Temperature and Extrusion Ratio on Plastic Strain

The strain distribution and the complexity of metal flow in the die are seen from the contour plots (Figs. 5 (a)-5(c)). It can be observed from the strain plots that in all the cases of extrusion ratios the maximum strain occurs in the die entry and exit areas. This has good agreement with the literature[16]. Whereas when the effect of friction is neglected, the extrusion strains are more observed in the working part of the die[11]. From Fig. 4, it is observed that the plastic strain increases as the billet temperature increases from 350 °C to 400 °C. At a billet temperature of 450 °C, the plastic strain is found to be the lowest. With further increase in billet temperatures, say, for 500 °C and 550 °C, the value of plastic strain is found to increase again. The plastic strain is found to be the lowest at 450 °C for all the extrusion ratios. The increase in strain in the initial regime is due to the initial work hardening of alloy. The sudden decrease in the strain at the temperature of 450 °C was due to the work softening/dynamic recovery of aluminium alloy due to plastic deformation process. At this temperature, the rate of work hardening is offsetting due to the work softening effects of dynamic recovery[17].

During the hot extrusion process, initial work hardening followed by dynamic recovery or softening happens. Aluminium and its alloys with high stacking fault energy exhibit a high rate of dynamic recovery, which hinders dynamic recrystallisation to a certain extent. But with further increase in temperature beyond 450 °C, due to growth of precipitates to larger size called secondary recrystallisation, there is a significant decrease in the rate of work softening against work hardening. This leads to the increase in plastic strain compared to that occurred at lower temperatures[18]. In this region, the dislocation density reaches such high levels that rate of strain hardening also increases and attains the peak. This causes the peak strain at high temperature of 550 °C. The effect of billet temperature rise during the extrusion process was neglected in this study. Similar behaviour is observed for all the extrusion ratios.

It is also observed that for the extrusion ratio of 4:1, the rate of increase of plastic strain in the initial regime, the rate of decrease for the billet temperature of 450 °C, and the rate of increase with further increase in temperatures of 500 °C and 550 °C, is found to be higher compared to that of extrusion ratios. At higher extrusion ratios (8:1 and 15:1), the similar trend is observed but at a slower rate. This is attributed to the softening effect due to temperature rise in the material. It is also found that the plastic strain increases with increase in extrusion ratio and a peak strain of 1.503 is recorded at an extrusion ratio of 15:1 for a billet temperature of 550 °C.

### 5.2 Effect of Temperature and Extrusion Ratio on Strain Rate

The strain rate is an important factor that has an influence on any forming process. It influences the forming process at varying degrees depending upon the processing temperature. In the present work, the strain rate is found to vary with the billet temperature as seen from Fig. 6. It is observed that for extrusion ratios, 4:1 and 8:1, the strain rate increases as the billet temperature increases from 350 °C to 400 °C due to initial work hardening. At a billet temperature of 450 °C, there is a decrease in the strain rate to the tune of around 49 per cent compared to that at 400 °C which is due to work softening. The decrease in strain rate causes a reduction in flow stress, which is favourable for extrusion. With increase in temperature beyond 400 °C the movement of dislocations gets easier and they readjust due to stresses locked in the lattice. Some dislocations having opposite sign may annihilate each other. This is called recovery process in which the residual stresses are reduced. With further increase in the billet temperature i.e. at 500 °C and 550 °C, the strain rate increases. In this region, work hardening was found to be dominant, leading to an increase in the strain rate. For the extrusion ratio of 15:1, the trend is similar except that the strain rate decreases till 450 °C. And

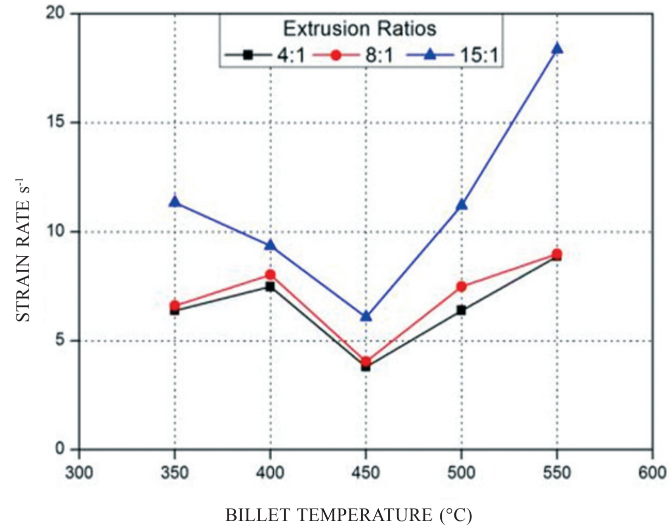



**Figure 6. Effect of extrusion ratio and temperature on strain rate.**

for this higher extrusion ratio, the rate of increase in strain rate at temperatures of 500 °C and 550 °C is higher compared to the lower extrusion ratios. The value of strain rate is found to be the highest for an extrusion ratio of 15:1 and at a billet temperature of 550 °C.

The value of strain rate increases as the extrusion ratio increases for all the billet temperatures (Figs. 7(a)- 7(c)). It is thus inferred from the results that, for this die geometry and die design, the strain rate is maximum at an extrusion ratio of 15:1.

Therefore, it is clearly understood that for the die design used in the present study, increasing the extrusion ratio results in increased strain rate and hence the extrusion load also increases.

Figure 8 shows the resultant extruded rod at the end of extrusion simulation carried out at an extrusion ratio of 8:1 and at billet temperature of 450 °C.

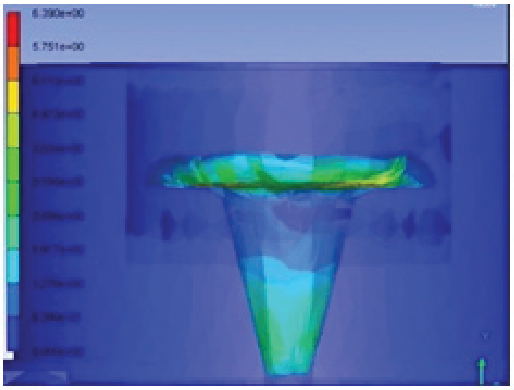
## 6. EXPERIMENTAL WORK

The composites were prepared by stir casting process. The aluminium alloy Al2014 was heated in the melting furnace, which was set to a temperature of 720 °C. The alloy composition is given in the Table 3.

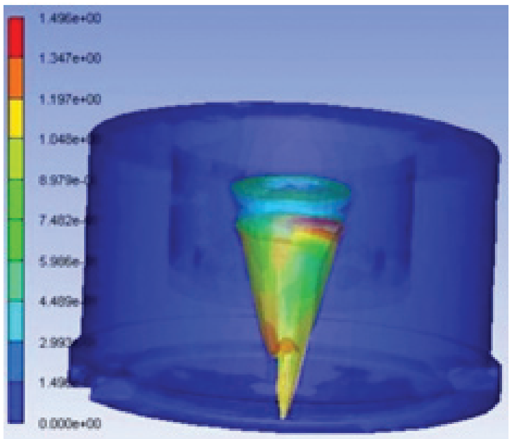
**Table 3. Chemical composition of Al2014 alloy**

| Elements | Cu | Cr | Fe | Si | Mg | Mn | Ti | Zn | Al |
|---|---|---|---|---|---|---|---|---|---|
| wt.% | 4.5 | 0.3 | 0.70 | 1.0 | 0.60 | 1.0 | 0.2 | 0.25 | Bal. |

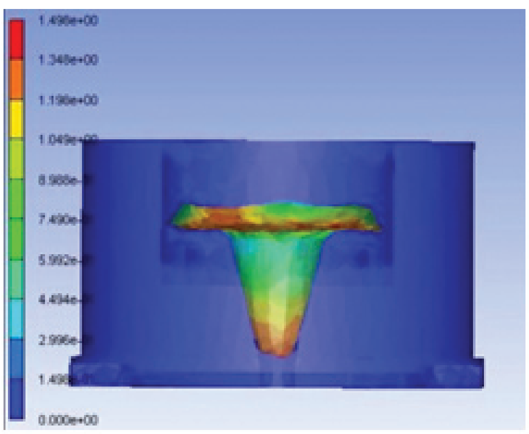
The silicon carbide particles of average size 30 µm (10 wt.%) was pre-heated separately in muffle furnace. After aluminium has reached the molten state, the silicon carbide particles were added and stirred at a speed of 400 rpm. After degassing, the molten mixture is poured in to the die with a cylindrical cavity of 70 mm diameter and 100 mm height. The cast composites were machined and subjected to T6 heat treatment[19]. The hot extrusion was carried out on the composite billet initially with an extrusion ratio of 1:4. An extrusion press



(a)




(b)




(c)

**Figure 7. Contour plots of strain rate at extrusion temperature 350 °C: (a) Extrusion ratio 4:1, (b) Extrusion ratio 8:1, and (c) Extrusion ratio 15:1.**

of 200 T capacity as shown in Fig. 9(a) was used in carrying out the hot extrusion. The machined composite billets were heated in a muffle furnace to 450 °C. The die was heated using a band heater to a temperature of 400 °C.

The die contains a base plate, a die container and a die insert. The die inserts used for the different extrusion ratios are shown in Fig. 9(b). The composite billet was pressed by moving the punch at a speed of 2 mm/s. The composite billet was passed through the die and the extruded rod of reduced diameter was made. Similarly, extrusions were carried out for the extrusion ratios of 8:1 and 15:1 also.

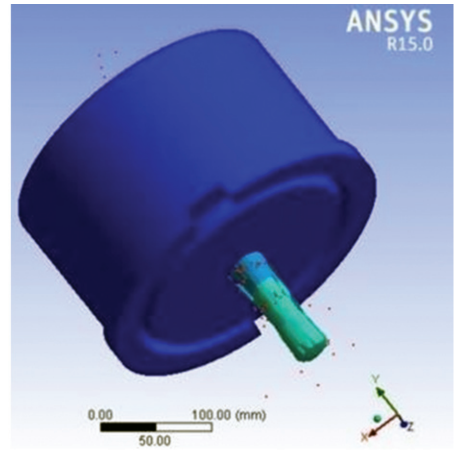
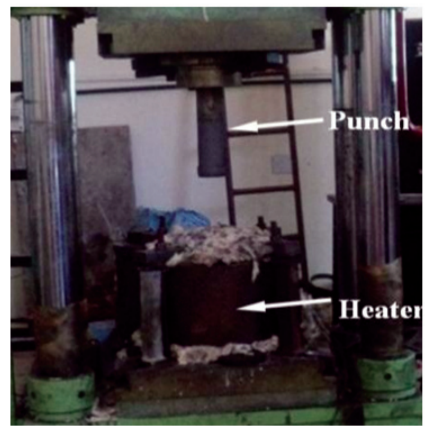
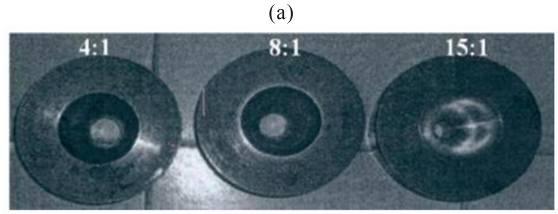



**Figure 8. Extrusion at the ratio 8:1 and billet temperature 450 °C.**




(a)




(b)

**Figure 9. Hot extrusion process setup : (a) Extrusion press with die assembly and (b) Die inserts used for different extrusion ratios.**

### 6.1 Microstructure

The microstructures of the as cast alloy and the hot extruded composites are shown in Figs. 10(a) - 10(d). The changes in microstructure as a function of extrusion ratio in turn the strain rate are studied by means of optical microscope make Mecji, Singapore. The microstructure of as-cast composite shows agglomeration of particles. However, the application of extrusion resulted in the breakdown of particles, uniform particle distribution and orientation of particles along the direction of extrusion. Second phase particles or inclusions will be distorted in the direction of plastic working and will be broken into fragments if they are more brittle than the matrix[15].

As discussed in section IV A, among the three extrusion ratios, the lower strain occurs at an extrusion ratio of 4:1. This is because, at low deformation (at 4:1), low dislocation densities due to the ease of cross slip, climb and dislocation unpinning are resulted. This is explained by the process of dynamic recovery, which involves annihilation of pairs of dislocations during strain hardening. This low dislocation densities result in a microstructure consisting of elongated grains as seen from Fig. 10(b). A more uniform distribution of reinforcement was achieved in the extrusion ratio of 8:1 as revealed in Fig. 10(c).

The average grain size was analysed from the optical micrographs using linear intercept method as per ASTM E112. The ASTM grain size No. and the corresponding mean grain diameter are tabulated in Table 4. The specimens were etched with 0.5 per cent HF to clearly distinguish the grain boundaries. From Table 4, it is seen that, extrusion imparts a fine grained structure on the composites.

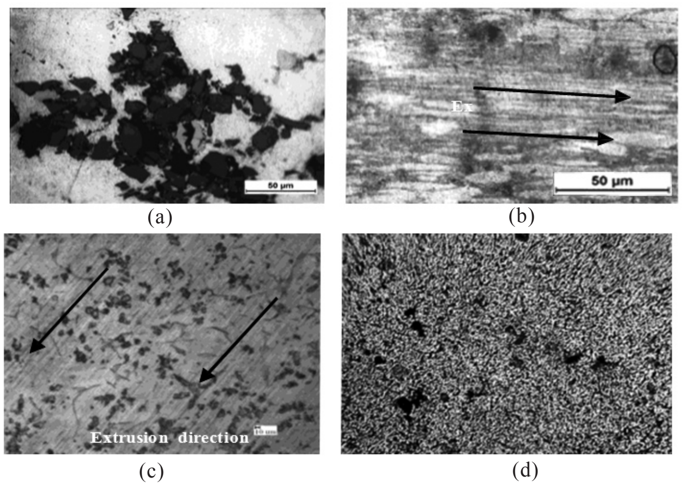



**Figure 10. Optical micrographs of composite samples: (a) As cast composite, (b) Composite extruded at 4:1, (c) Composite extruded at 8:1, and (d) Composite extruded at 15:1.**

**Table 4. Grain size values of as-cast and extruded composites**

| Material | Grain size (ASTM No.) | Mean Grain Diameter (µm) |
|---|---|---|
| As cast composite | 3.5 | 106.8 |
| Composite extruded at 4:1 | 4 | 89.8 |
| Composite extruded at 8:1 | 6 | 44.5 |
| Composite extruded at 15:1 | 5.5 | 53.4 |

For direct extrusion, the grain size is related to the processing parameters and has been established for many alloys as given in Eqn (3).

$$\delta^{-1} = A \ln Z - B \quad (3)$$

where $A$ and $B$ are material constants, $\delta$ is the grain diameter and Z is the temperature compensated strain rate.

From Eqn (3), it is found that the grain size decreases with increasing extrusion ratio. In the present study, it is found that for a given billet temperature, as the extrusion ratio increases from 4:1 to 8:1, the grain size decreases. However, with further increase in the extrusion ratio, (i.e. for 15:1), the grain size increases. This contradicts with the study of[20] who reported that at constant temperature, the linear relationships of average grain size-true strain rate curves of aluminium alloy have a negative slope. The reason for the behaviour in this study can be explained based on the billet temperature rise during extrusion. During extrusion, the billet temperature rises with increasing deformation i.e. strain rate. At higher extrusion ratio, as the strain rate of deformation increases, more heat is retained in the billet which leads to grain coarsening. Mohapatra and Maity[4] states that, the extrusion parameters affect the temperature of the billet at various places in the deformed zone, which directly affects the load requirement and microstructural changes[4].

### 6.2 Surface Quality of Extrudates

Figure 11 shows the samples extruded at different extrusion ratios. It is clearly seen that the surface of rods extruded at 4:1 and 8:1 were smooth and no surface defects were found. While the rod extruded at 15:1 appeared to a have badly roughened surface (Fig. 11(a)).

Along the axis of extrusion, the surface of the extrudate is found to have repetitive transverse cracks called 'fir tree cracking'. During axi-symmetric extrusion operations, two modes of fracture commonly occur, internal cracking (chevron) or external cracking (fir-tree). A closer look (Fig. 11(b)) of the surface indicates the presence of cracks due to hot shortness. In hot extrusion, the fir tree cracking is associated with hot shortness and the common cause is too high ram speed for the extrusion temperature and in turn, the ram speed is dependent on extrusion ratio. Similar observation is found by Prasad[21], *et al.* on AA 2124 + 30% SiCp. In their study, the integrity of the extruded composite rod was very good at a minimum extrusion speed of 1 mm/s whereas extrusion speeds of 10 mm/s and 100 mm/s resulted in fir tree cracking. While the study carried out by Duan[22], *et al.* indicates that the greater the extrusion ratio, the less possibility of occurrence of surface cracks. The maximum billet temperature and the allowable amount of deformation are determined by the temperature at which incipient melting or hot shortness occurs. Surface cracking is closely related to the temperature rise during extrusion[23]. If the heat generated near the die land area increases the local temperature above the solidus point, localised melting can occur, which can cause severe cracking of the surface. However, in FEM simulation, since the rise of billet temperature during extrusion was neglected the surface cracking was not observed.

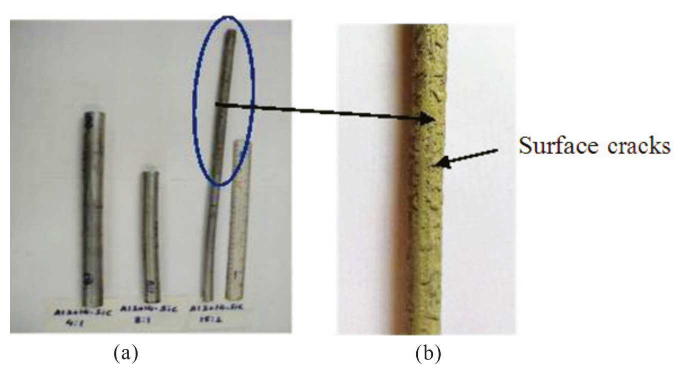



**Figure 11. Closer view of rod extruded at 15:1. (a) Extruded samples and (b) Close view.**

## 7. CONCLUSIONS

Finite element method has been successfully applied to study the effect of three different extrusion ratios (i.e., 4:1, 8:1, and 15:1) at billet temperatures in the range 350 °C to 550 °C in steps of 50 °C for the hot extrusion process of Al2014-SiC composite. Experimental hot extrusion was also carried out on the composite at a billet temperature of 450 °C for above three extrusion ratios. The following conclusions can be drawn based on the above mentioned analysis and experimental study:

- For the extrusion conditions discussed in this paper, the lowest plastic strain and strain rate was observed at the billet temperature of 450 °C.
- Both the plastic strain and strain rate increases with extrusion ratio for all the billet temperatures. And, of the three extrusion ratios 4:1, 8:1, and 15:1, higher plastic strain and strain rate was found to occur at the highest extrusion ratio at a billet temperature of 550 °C.
- The microstructural analysis revealed that the grain size is dramatically affected by the strain rate. Grain size analysis of composites extruded at 450 °C and at three different extrusion ratios viz. 4:1, 8:1, and 15:1, revealed that the optimum grain refinement occurred at extrusion ratio 8:1.
- However, higher extrusion ratio of 15:1 has resulted in occurrence of hot shortness and surface cracks. It is also found that extrusion ratio has got the strongest influence on the initiation of surface cracks.

The results of this study helped in arriving at the optimum extrusion ratio and billet temperature to carry out further extrusions.

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