Effect of Cold Forging on Microstructure and Mechanical Properties of Al/SiC 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 2.5, 5, 7.5 and 10%. Further, the deformation characteristics during open-die forging of Al-SiC composite at cold conditions was investigated. Cast and forged composite material was subjected to hardness test, tensile test and impact test. The grain size, microstructure behaviour was investigated using optical microscope. The results show that hardness and strength of Al-SiC composite increases and ductility decreases as compared to Al alloy in both as-cast and forged conditions. Optical microscope images showed that the distribution of SiC in Al matrix was more homogeneous in a forged composite as compared to cast one and reduction of porosity was found. Further, it showed that due to forging cycle the grain size was reduced by 30% to 35% from initial size.

Keywords: Mechanical properties, Composites, Al/SiC and Microstructure

1. Introduction
In the twenty first century, it has a highly demand of lightweight materials, particularly in a fast rising automotive and aerospace industry. In current times for the weight reduction purpose Al, Ti, and Mg alloys are used, but aluminium is not sufficiently rigid or strong for many applications and reinforcement is essential[1-2]. The aluminium based MMCs is outstanding candidates of highly ductile matrix phase and high strength or hard reinforcing phases. But they are weak in formability of MMCs associated with particle fracture and matrix-reinforcement decohesion. Conventional fabrication methods of MMCs produce low ductility due to high brittle reinforcements and uneven microstructure such as porosity, and agglomeration[3-5].

To overcome the above cited problems with using secondary forming process as rolling, extrusion and forging, to get a final module. These processes minimise or eliminate porosity, improve the particle distribution and to make the strong interfacial bond between matrix and reinforcement phase. Also, cold forging and extrusion operation of composite material gives a better secondary operation for gain economic advantages over other process such as net shape and size, improved hardness, surface quality is improved, increase accuracy and improve fatigue strength properties. During the operation of
cold forging of metal matrix composite material, the stress generated in forming region is shifted to compressive side or outer surface and crack free component can be produced. It is clearly that the most of researchers has working or concentrated on the studying extruded and rolling behaviour of aluminium based composites[5-7]. Whereas comparatively few researchers are studied on the effect of the forging operation on the aluminium based MMCs composite[8-10]. The objective of this study is to estimate the effect of cold forging on mechanical properties like hardness, impact strength and tensile properties at room temperature.

2. Experimental study

Al6061 is widely used in automobile and aerospace industries, and its physical, thermal, chemical and composition are shown in below Table 1.

| Table 1: Chemical composition of Al6061 Aluminium alloy |
|--------------------------------------------------------|
| Al         | Mg | Si | Cr | Mn | Ti | Cu | Fe | Zn |
| 95.8-98.6  | 0.8-1.2 | 0.4-0.8 | 0.04-0.4 | 0.15 | 0.015 | 0.15-0.4 | 0.7 | 0.25 |

Silicon carbide (SiC) in the crystal lattice and size is 25 to 30µm was used as a reinforcement. Before mixing in aluminium matrix is heated in an aging furnace for proper garn size. Different percentage of SiC (2.5, 5, 7.5 and 10% by weight) were used for mixing with Al 6061 matrix alloy.

The Al-SiC MMCs material fabricated with the help of stir casting method. In this process, first aluminium is placed on the aging furnace with help of crucible, and its heated above its melting point at 800°C. After 3 hr to 4 hr aluminium is completely melted. The required quantity of SiC particles as per weight percentage are preheated to 350°C. The preheated SiC particle are added to the aluminium molten metal and continuously. For the proper mixing of aluminium molten metal and SiC particle, the stirrer is rotated at an speed of 450 rpm for 5 min. After completing stirring operation the molten metal of mixed Al-SiC is poured into a fixed mould of cast iron of size D = 60 mm and h = 180 mm, at same time temperature of casting is then lowered gradually. After 24 hr the casting get solidified and the castings are taken out from the mold and cut as per required shape and sizes (D = 60 mm and h = 50 mm) for forging operation.

After the casting, the next step is turning the moulded composite to required dimensions. After completing the casting of Al-SiC metal matrix composite, the specimen subjected to forging operation. Further, annealing operation was done in aging furnace and try to reduce hardness upto 40 BHN. Hydraulic press is a device using a hydraulic cylinder to generate a very high compressive force and its depends on the Pascal’s principle. In cold forging applied load on the billet or workpieces of very high.

The sample for microstructural investigation by using optical microscope, where cut from the casted and forged Al-SiC composites material along the direction of forging. After successfully completion of cutting in forging operation the specimen is now required to undergo fine polishing process. Though we have taken care to get best surface finish in turning operation, but it is not enough to get the microscopic image of particles at this stage. Therefore the polishing is done initially by using silicon carbide grit of size 200, 600, 800, and 1200 in an order given. This process is repeated for all size of grit up to 1200 and for all samples to be prepared using polishing machine.

Green cloths are use for specimens are washed with water in between to prevent carryover of coarse grit from previous steps. After fine polishing over then samples are etched with Keller’s reagent (2.5 ml HNO₃, 1.5 ml HCl, 1.0 ml HF, 95.0 ml Water) and dried by an electric dryer. Further microstructure images taken from the both casted and forged Al-SiC composite from Optical
microscope as per IS:7739 PART III-1976(RA) in the Raghavendra Spectro Metallurgical Laboratory, Bangalore. The grain size of both cast and forged composite performed in gray threshold method in an optical microscope.

The hardness test on a matrix alloy and composite were conducted using Vickers cum Brinell hardness testing machine. The maximum capacity of required load is 250 kg for Brinell test and 120 kg for Vickers Test. A ball and diamond indentor used for Brinell, and the Vickers hardness test respectively. Based on the material ductility load is subjected to 31.25 kg for Brinell, and 20 kg for Vickers hardness test. The full load is normally applied and dwell time is 20-30 seconds Al-MMCs composite material. The indentation diameter left on the test specimen of Al-SiC material is measured with traveling microscope. The hardness number is evaluated by using the formula of applied load to the indentation surface area. Hardness experiment done along the direction of forging operation.

The Charpy test specimen sample is made up by as per ASTM E23. The dimensions of sample is 10 x 10 x 55 mm³, at 45⁰ V notch at 2 mm depth and root radius of 0.25 mm. These sample are machined from the casted and forged Al-SiC composite material at the reduction ratio of 20%, 40% and 60% cut along the forging direction.

After completing, the forging operation next step is investigation of mechanical properties of Al6061/SiC composite material. Mechanical experiment of composite is done in different testing like hardness, tensile, impact, optical microscope.

3. Results and Discussion

Figure 1. Optical micrographs of casted and forged composite A) Al Matrix alloy, B) Al-5% SiC composites, C) Al-10% SiC Composites. (1- ascast and 2- Forged)

Figure 1. shows optical microscope photos of Al alloy and Al–SiC MMCs composites in casted and cold forged conditions. It is clearly observed that the distribution of SiC particle in forged parts is more uniform than the casted part. Al alloy in forged composite is more closer than the casted ones. It’s represent the reoriented and re-crystallization of Al-SiC during the cold forging process[11]. As it
is seen in figures good interfacial bond exists between the aluminium matrix and silicon carbide. There is no pullout of SiC and Al particle, and crack or fracture of SiC particles is observed in a forged part. The size of SiC particle in forged parts for the given reinforcement material is a smaller than the related cast composites material. The particle size of SiC in cast and forged composite material in the range of 25–30 µm and 15–20 µm resp. This is observed due to the very high compressive forces on the SiC particles during the cold forging process. Further is observed with the help of microphotographs of cast and forged composites material, that the SiC particles are re-oriented in the direction of metal flow during forging process.

Figure 2 shows the effect of forging and wt% of SiC particles on hardness of Al-SiC composites. Here it is conclude that there is a slightly improved in hardness with an addition of SiC in Al matrix alloy and significantly improved in hardness by forging[12]. The hardness is increased by 7% and 10% with the addition of 5 wt% and 10 wt% silicon carbide particles in matrix alloy respectively. Further applied forging of different percentage, such as 20%, 40% and 60% of forging hardness is increased by 16%, 33% and 45% of Al–10% SiC composites respectively when compared with their casted. Due to the higher difference in coefficient of expansion between SiC and Al alloy results in a higher density of dislocations leading to higher hardness.

Figure 3 shows the effect of reduction ratios and wt% of SiC particles on the ultimate tensile strength of Al-SiC composites. It indicate that increase the reduction ratios in cross sectional area of Al alloy, Al-5% SiC and Al-10% SiC composites leads to an increase in the ultimate tensile strength (UTS). Further, the generation of high dislocation densities due to difference in co-efficient of thermal expansion between matrix and reinforcement may also be responsible for improved tensile strength. It shows the combined effect of work hardening and redistribution SiC particles in Al matrix during cold forging. The increase in strength is more in the cold forged samples than in the casted samples. It is understood that strain hardening tendency is higher in the case of cold forging. UTS increased by 25.93%, and 60.43% for has been observed in as 20% and 40% forged cycle of Al–10 wt SiC
composites respectively when compared with their casted. By adding of 5\% wt and 10\% wt SiC into the Al6061 matrix, UTS increased by the 0.68\% and 1.52\% respectively at the 40\% forged cycle.

![Graph showing effect of forging cycle and wt% of SiC particles on UTS of Al-SiC composites.](image1)

**Figure 3.** Effect of forging and wt\% of SiC particles on the ultimate tensile strength of Al-SiC composites.

Figure 4. shows the effect of forging cycle and wt\% of SiC particles on the ductility (% of elongation) of Al-SiC composites. It is observed that addition of SiC leads to the drastic reduction in ductility of Al6061–SiC composites for both as cast and hot forged conditions. The reduced ductility of Al6061–SiC composites with increased content of SiC particles in both as cast and cold forged conditions can be attributed to the stress concentration effects at the interface of the matrix and SiC particles. The ductility values of cast Al alloy, cast Al–5 wt\% SiC and cast Al–10 wt\% SiC composites are 9.75\%, 9.68\% and 9.59\% respectively. In case of 40\% forged of Al alloy, Al–5wt\% SiC and Al–10\% SiC composites the ductility values are 9\%, 8.62\% and 8.58\% respectively. Ductility reduced because of the recrystallization and grain modification in matrix material during forging of alloy and developed composites. All these factors together improve the interfacial strength and ductility of the matrix and composites[13].

![Graph showing effect of forging and wt% of SiC particles on ductility of Al-SiC composites.](image2)

**Figure 4.** Effect of forging and wt\% of SiC particles on the ductility of Al-SiC composites.
Figure 5. shows the effect of forging and wt% of SiC particles on the impact strength of Al-SiC composites. Here is noted that the slightly increasing in impact strength with the addition of SiC particles in Al6061 matrix alloy and significantly improved by forging. Further improve the impact strength of 24.4% and 52.78% increased by the addition of 5% and 10% silicon carbide particles in matrix alloy respectively at casted as well as forged condition. Further reduction ratios of different percentage, such as 20%, 40%, and 60% of forging impact strength is increased by 28.37%, 63.7% and 87% of Al–10% SiC composites respectively when compared with their casted[14-15].

4. Conclusion

- In cold forging billet can be successfully compressed to a height reduction by 35% to 40% without fracture. Billet start to damages only after a reduction in height by 40% to 50% and maximum damages at 60%.
- The Ultimate tensile strength of 40% forged Al/10 % SiC composite increased from 330 MPa to 430 MPa, and the hardness, increased from 39 to 62 BHN through the cold forging. Impact strength slightly increased from 2 to 6.5 Nm in cast and forged composite
- The ductility of the composites is decreased with the increasing amounts of SiC, and with the application of forging a substantial improvement in ductility is obtained.
- With increasing the forging cycle in cast MMCs, the hardness, increased and after a certain forging cycle the hardness starts to decrease. The hardness is high at the 60% degrees of deformation of the casting compared with Al alloy and 10% wt SiC of Al-SiC composite casting.
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