Chapter 2: Experimental Work

This chapter deals with the various procedures employed during experimental work. It consists of the casting of different Al-Si alloys, preparation of dies and test samples for forging, and different techniques to characterize the forged samples. Figure 2.1 shows the block diagram of the complete experimental work.

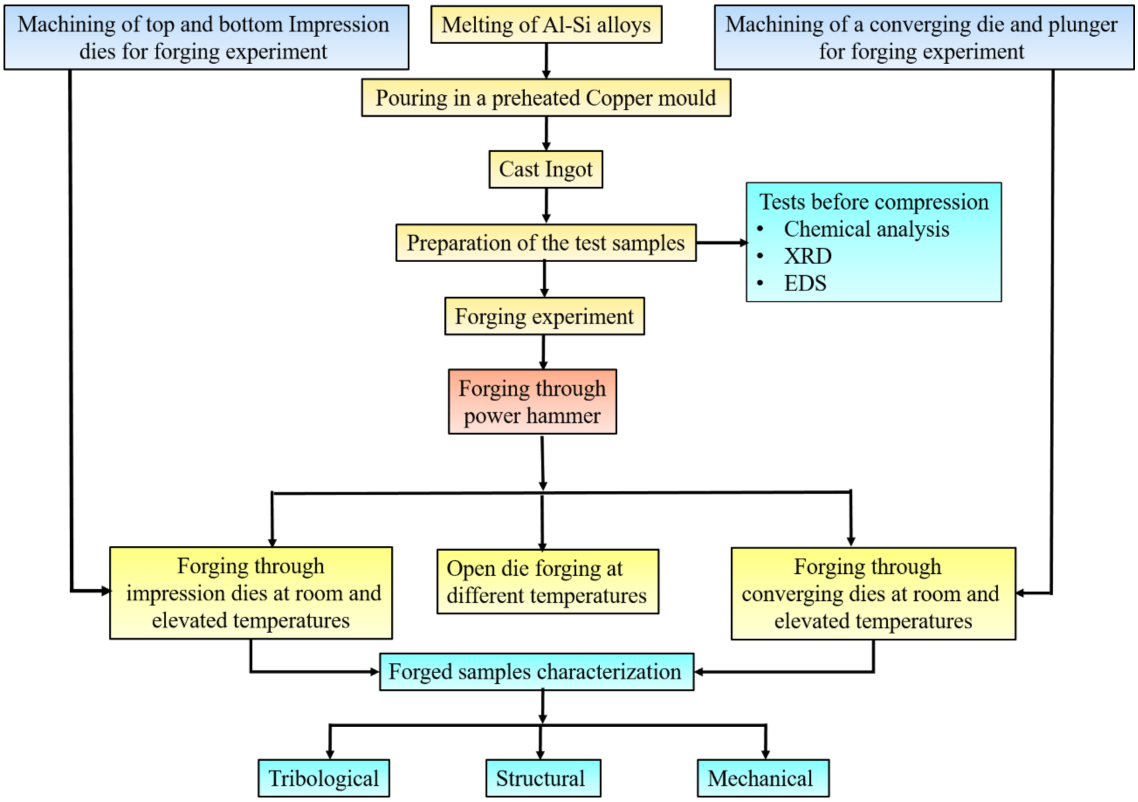

Figure 2.1 Block diagram of the experimental work

The detailed experimental procedures are as follows:

2.1 Preparation of dies and mould

The impression and converging die set-ups both were made from H11 die steel material. The required dimensions of the die impressions and size were machined from H11 die steel bar and after finishing they were heat treated. The heat treatment procedures consist of hardening of die set-ups at 800°C for 1 hour soaking time. After this, the hot die set-ups were again soaked for 20 + 5 min. (For each 25 mm) at 1010°C, and cooled at room temperature. Furthermore, the die set-ups were tempered at 540°C for 2 hours to induce toughness and reduce excess hardness. After this fine sized emery papers and acetone were used to clean the die set-ups.

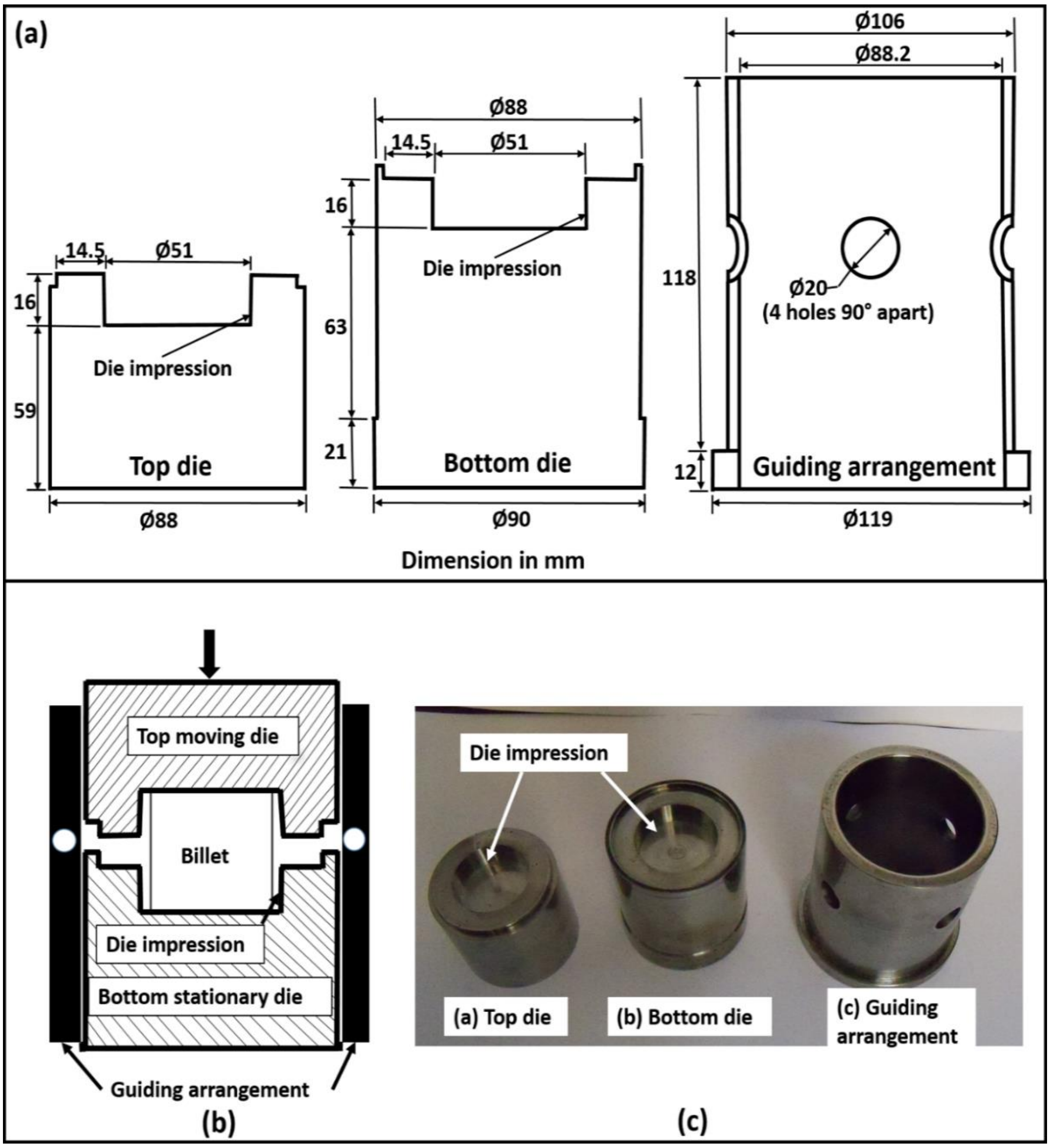

Figure 2.2 Impression die set-ups (a) dimension of the die impression, (b) schematic diagram, and (c) photograph of die set-ups and guiding arrangement

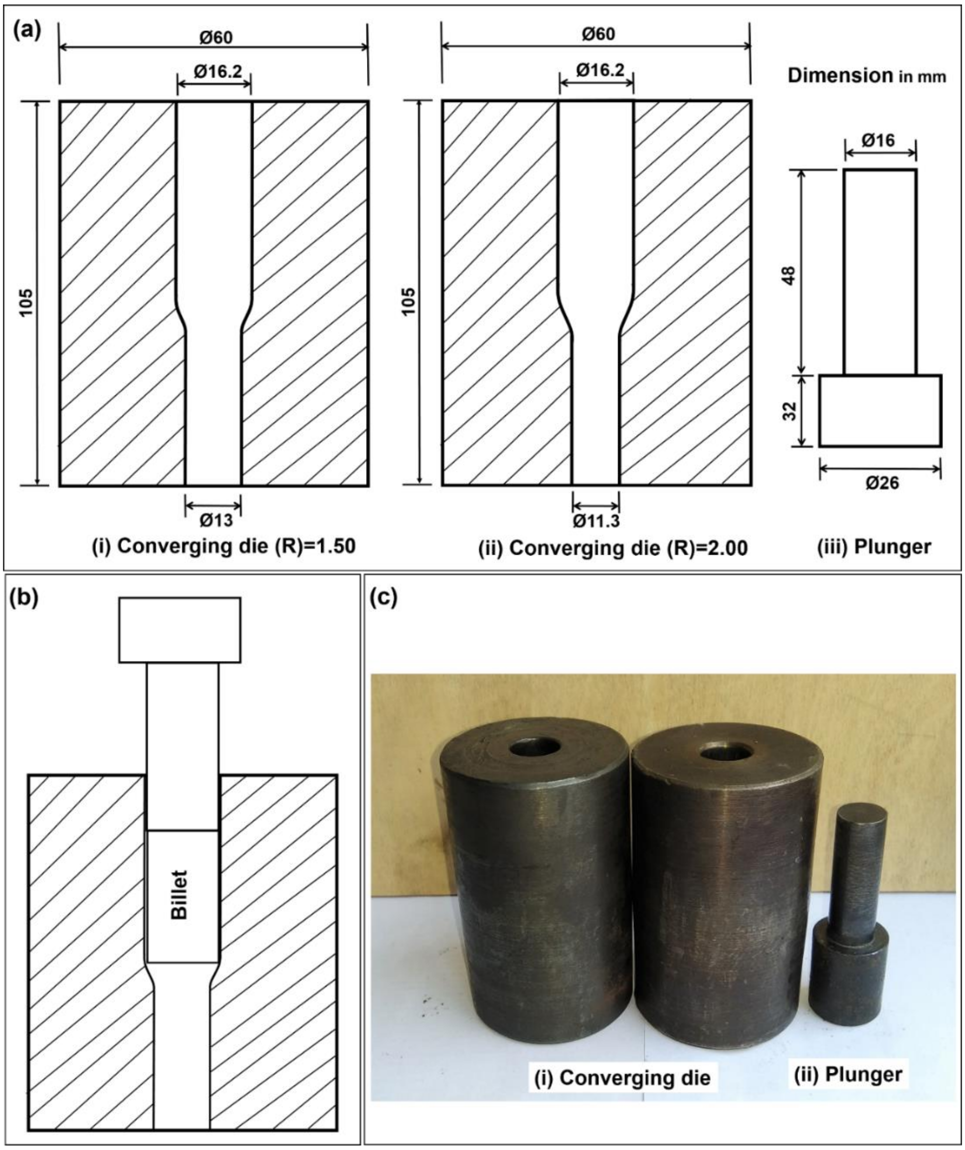

Figure 2.3 Converging die set-ups (a) dimension of the die, (b) schematic diagram and (c) photograph of die set-ups and guiding arrangement

In impression die a guiding arrangement made from medium carbon steel was prepared to ensure proper alignment of top and bottom dies during forging. Figure 2.2 shows the dimensions (mm) and a photograph of the impression top-bottom dies and guiding arrangement (medium carbon steel). Figure 2.3 shows the dimensions (mm) and a photograph of the converging die and plunger. A taper shaped copper mould was prepared to ensure complete filling of the mould cavity and restricts entrapment of unwanted gases. Also, copper possesses good thermal conductivity that permits the molten metal to cool rapidly.

2.2 Casting of Al-Si alloys

Table 2.1 Chemical composition of the as-cast alloys

Elements (Wt.%)	**Al-18Si-2.5Cu-0.6Fe alloy**	**Al-11Si-2.5Cu-0.6Fe alloy**	**Al-7.4Si-2.5Cu-0.6Fe alloy**
Si	18.0	11.0	7.40
Cu	2.50	2.50	2.50
Fe	0.60	0.62	0.63
Mg	0.60	0.04	0.05
Zn	0.30	0.05	0.14
Mn	0.02	0.02	0.12
Cr	0.03	0.02	0.04
Al	Balanced	Balanced	Balanced
Designa-tion	**Alloy A**	**Alloy B**	**Alloy C**

An electric resistance heating furnace was used for controlled melting of the Al alloy containing 18, 11 and 7.4 wt% silicon, 2.5 wt% copper and 0.6 wt% iron in the form of the powder at 750°C. After melting, the temperature of the furnace was increased to 780°C and maintained for 20 minutes for the purpose of superheating. After complete melting of alloy, solid hexachloroethane (C_2C_{l6}) degasser powder was mixed in the melt to remove the unwanted gases from the metal. The molten metal was poured into the preheated (190°C–200°C) copper mould at 710°C. Atomic Emission Spectrometer (FOUNDRYMASTER, S/N01J0054) was used to analyze the chemical composition of the as-cast alloys, as shown in Table 2.1. X-ray diffraction (XRD) analysis was carried out to characterize the phases present in the as-cast alloy using Rigaku x-ray diffractometer. The peaks were identified using the International Centre for Diffraction Data (ICDD) PDF database.

2.3 Preparation of test samples for forging operations

The test samples were prepared from cast ingot for both impression and converging dies forging experiments. For impression die forging, three sets of test samples with different aspect ratios (h/d = 1.20, 1.0 and 0.80) were machined from cast ingots. To ensure complete die filling, volume of the test samples (Figure 2.4) was almost kept constant against varying h/d ratio for the designed die impression Ø51 mm × 32 mm deep. The dimensions of the test pieces are shown in Table 2.2. Further, the solid cylindrical test samples were also machined from cast ingot for converging die forging experiments. The dimensions of the test samples (Figure 2.5) are as follows:

(i) Ø16 mm × 42 mm length (For reduction ratio 1.5)

(ii) Ø16 mm × 37 mm length (For reduction ratio 2.0)

Table 2.2 Dimensions of the die impression and test samples

Parameters	Diameter (d) mm	Height (h) mm	Aspect Ratio (h/d)	Volume (mm^3)
Closed die impression	51.00	32.00	0.63	65337
Test samples	47.00	37.60	0.80	65201
	43.60	43.60	1.00	65065
	41.00	49.30	1.20	65320

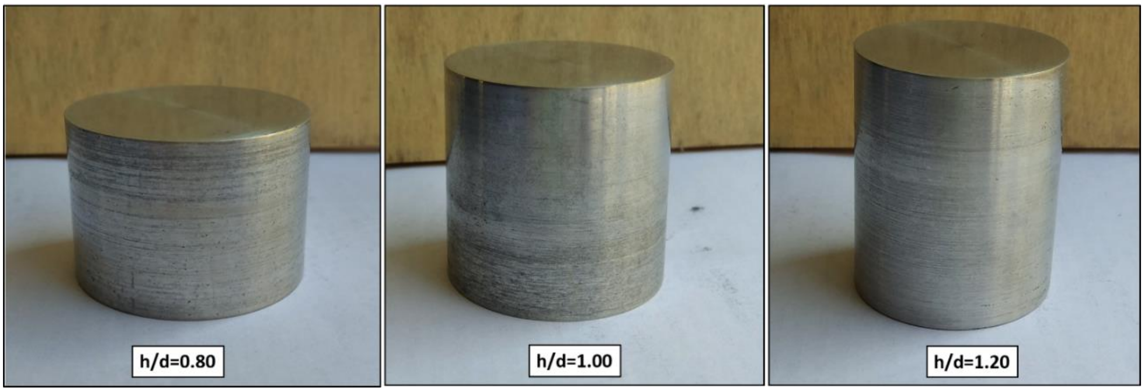

Figure 2.4 Photograph of undeformed test samples for impression forging

Figure 2.5 Photograph of undeformed test samples for converging die forging

2.4 Open die and impression die forging

The test samples of different aspect ratios were forged in open die at room and elevated temperatures under lubricated and unlubricated interfacial friction conditions. The test samples (h/d=1) were forged between the flat top and bottom die platens of power hammer in open die conditions at 300°C processing temperature. Further, high-speed forging was done in a pneumatic power hammer at elevated temperatures (300, 400, and 500°C) in both lubricated conditions. Prior to forging, the test samples were kept at the corresponding working temperature for approximately one hour for compositional homogenization of the alloy. Fine graphite powder was used as a lubricant during the forging operation. High-speed forging was performed on pneumatic power hammer, having a minimum 700 Kg m of blow energy as shown in Figure 2.6(a). The forged billets were taken out from the die and samples were prepared for microstructural studies, tensile, hardness and wear tests.

(a) (b)

Figure 2.6 Photograph of the Pneumatic Power Hammer with (a) impression die set-ups, and (b) converging die set-ups

2.5 Converging die forging

The test samples were forged in the converging die with reduction ratios (R) of 1.5, and 2.0 at 300, 400, and 500°C. Prior to forging, the test samples were kept at the corresponding working temperature for approximately one hour for compositional homogenization of the alloy. Fine graphite powder was used as a lubricant during the forging process. High-speed forging was also performed on pneumatic power hammer, having a minimum 700 Kg m of blow energy as shown in Figure 2.6(b). After the forging, the billets were allowed to cool in the die to room temperature. The forged billets were taken out from the die and samples were prepared for microstructural studies, tensile, hardness and wear tests.

2.6 Microstructural studies

Microstructural examinations of forged samples in both die set-ups were conducted to study the grain size and second phase morphology of the alloy. For microstructural examination of the as-cast and forged billets, test samples were taken from the middle portion of the billets and were polished using standard metallographic techniques and finally etched with Keller's reagent. Microstructures of the test samples were imaged using an optical microscope (ZEISS) and a scanning electron microscope (SEM) equipped with EDS (ZEISS) at different magnifications. The ImageJ software was used to determine the primary and eutectic Si particle size.

2.7 Mechanical properties evaluation

The tensile test samples of the as-cast and forged billets (from Fig. 2.7(a) impression die, and (b) Section III in converging die) were machined according to ASTM E8 standard with gauge length and gauge diameter of 16 mm and 4 mm (Fig. 2.7(c)), respectively. The tensile tests were performed on Instron (Model-4206) at 1 mm/min strain rate, at room temperature. Three samples were tested for each condition. The samples for hardness test were machined from the center of the as-cast alloy, and the forged billets (from Fig. 2.7(a) impression die, and (b) Section III in converging die). Three samples were also used for measuring the hardness of the alloy, and the hardness test was conducted using a semi-automatic Vickers Microhardness Tester at 100 g indentation load and 10 sec dwell time. Ten indentations were made for each condition.

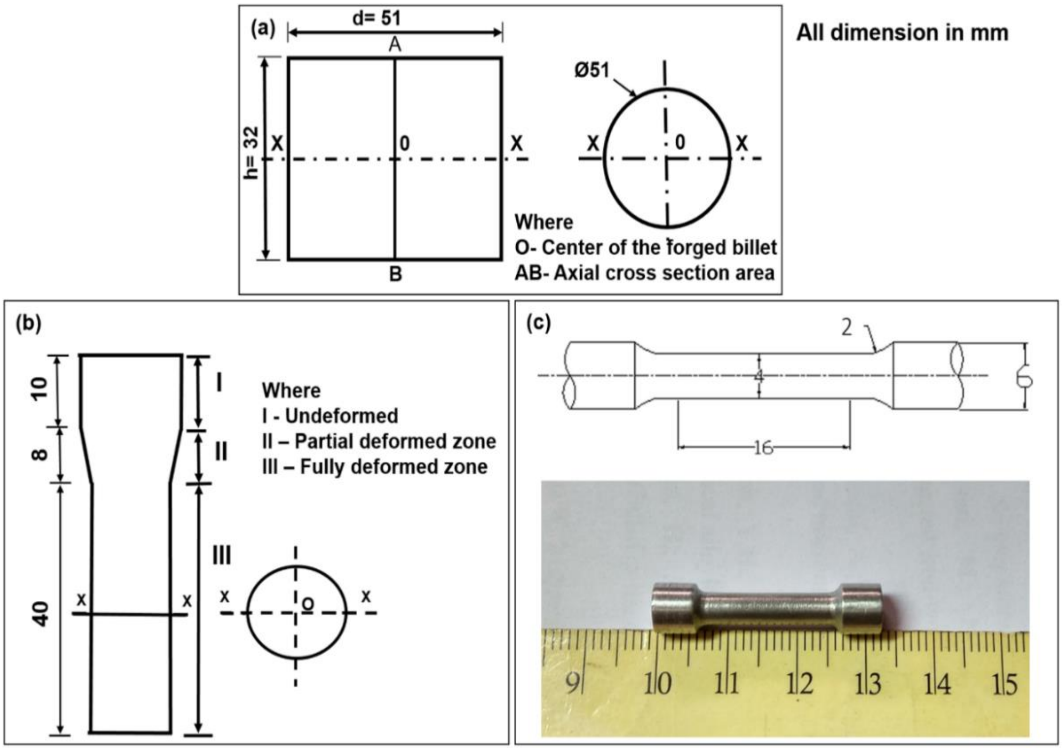

Figure 2.7 Schematic diagram of a forged billet in (a) impression die, (b) converging die, and (c) tensile specimen

2.8 Wear test

Wear tests of the as-cast and forged billets (from Fig. 2.7(a) impression die, and (b) Section III in converging die) were performed on the pin-on-disc wear testing machine using ASTM G99 standard under dry condition. The cylindrical pin of 8 mm diameter was mounted against the sliding, the disc made of stainless steel (EN31) with the surface hardness of 63HRC. Wear tests were performed under different normal loads of 10, 20, and 30 N at a constant sliding velocity of 1.3 m/s for a distance of 2260 m. Wear tests were replicated thrice for the accuracy of the results. The weight loss during the wear test was measured using an electronic balance with a resolution of 0.0001 g. The worn surface morphology of these test samples was examined under SEM and a semi-contact mode Atomic Force Microscope (Model no. NTEGRA Prima and made by NT-MDT spectrum Instruments, Russia).

The processing conditions such as open die forging, impression die forging and converging die forging, and processing parameters such as working temperatures, aspect/reduction ratio and interfacial lubrication discussed above in this chapter will be used for the discussion in preceding chapters.

The next chapter 3 deals with deformation behavior and tribo-mechanical properties of the complex hypereutectic Al-18Si-2.5Cu-0.6Fe alloy during forging.