Chapter-1: Introduction and Literature Review

During the last few decades aluminum alloys have assumed an important position in industries as they are being used successfully in a wide range of applications. Aluminum-Silicon (Al–Si) alloys are one of the most promising materials for automotive and aerospace industries with acceptable mechanical properties including low density, superior corrosion resistance, low thermal expansion, and excellent tribological characteristics (Rajaram et al., 2010; Kumar and Wani, 2017; Li et al., 2018). Further, the current engineering applications such as automotive and aerospace industries demand light-weight materials having high strength and excellent wear resistance to prevent premature failure of the components. Al–Si alloys are the best suited to meet all these requirements. The properties such as tensile strength and corrosion resistance of the Al–Si alloys can further be enhanced by alloying with the small amount of copper and iron to extend its suitability for the particular application (Ceschini et al., 2009; Wang et al., 2010).

Tribo-mechanical characteristics of the metallic material depend on the shape and size of the second phase particles present in the matrix and also their distribution, and physical properties. The presence of hard second phase particles in the soft matrix has been observed to cause significant enhancement in tribological properties (Shah et al., 2007; Dwivedi, 2010). However, such materials with coarse or irregular shaped second phase particles exhibit poor tribo-mechanical properties and undergo catastrophic failure during service.

The hypoeutectic Al-Si alloy produces the coarse α-Al dendrites and needle-shaped eutectic Si due to slow cooling rate. However, the higher amount of silicon content in conventionally cast hypereutectic Al–Si alloys often produces coarse primary Si along with needle-shaped eutectic Si particles. Moreover, these Si particles are non-uniformly distributed in the Al matrix, which impair the performance of the alloy. Therefore, it is highly essential to modify such detrimental microstructural constituents into fine and uniform dispersion in the Al matrix to enhance the tribo-mechanical properties of such alloy (Raju et al., 2012; Meenia et al., 2016).

1.1 Background of Aluminum and its alloy

Aluminum is the second highest used metal in the world after steel. Figure 1.1 shows the share of total use of aluminum in various industries in the world (Global demand for semi-finished aluminum products in 2016, by sector, 2018).

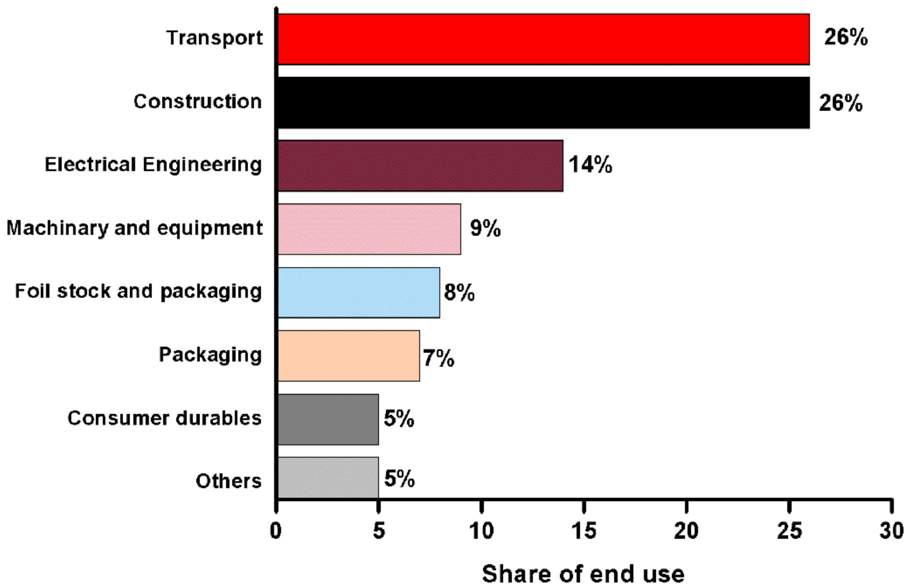

Figure 1.1 Share of aluminum and its alloys in various industries (Global demand for semi-finished aluminum products in 2016, by sector, 2018)

Aluminum and its alloys are most widely used in transportation and construction sectors due to its desirable mechanical properties. The transportation sectors demand light material to produce different parts of vehicle and, thus in turn enhance the fuel efficiency and reduces the amount of CO_2 emission. Due to this, the consumption of aluminum and its alloy increases in manufacturing of vehicle components.

Figure 1.2 shows the status of various vehicle components currently being produced using different manufacturing techniques. In the beginning, casting was used as the major manufacturing techniques for producing different automotive parts. However, the production of such components through other metal forming techniques increased during last 5 years and it is expected that it will increase further in future as shown in Figure 1.2 (Drucker worldwide 'Aluminum content in cars: summary report', June 2016). The components produced through casting techniques suffer severe casting defects and possess relatively low mechanical properties, whereas the metal forming techniques produce the component having excellent mechanical properties without any defects, therefore these techniques increase nowadays.

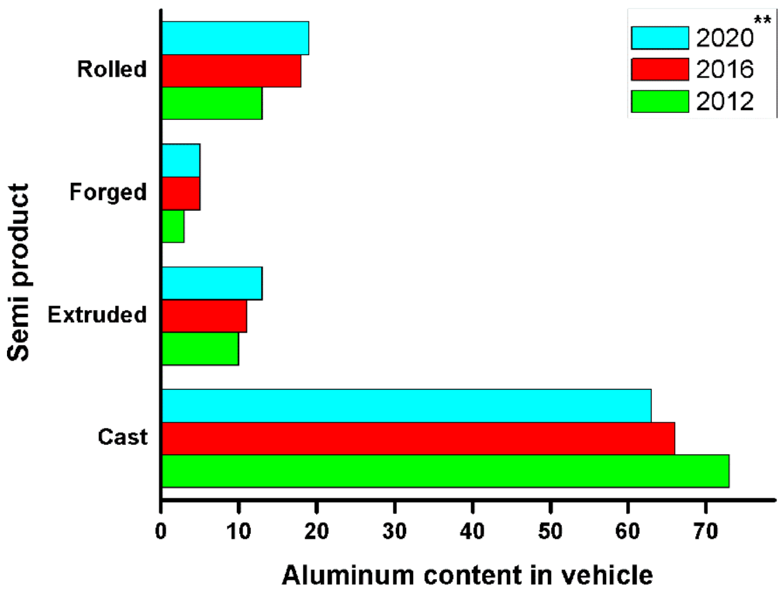

Figure 1.2 Production of various vehicle components by different manufacturing techniques (Drucker worldwide 'Aluminum content in cars: summary report', June 2016)

1.2. Types of Al alloy

Pure aluminum metal is light in weight and known for ductility and softness. The mechanical properties of aluminum further improve due to alloying of one or more elements in the metal. Different alloying elements such as Fe, Cu, Zn, Mn, Si, and Mg are added to aluminum in commercial alloys. The aluminum alloys are available in two different categories of wrought Al alloy and cast Al alloy. The wrought Al alloys are present in the series 1xxx-pure Al, 2xxx-Cu, 3xxx-Mn, 4xxx-Si, 5xxx-Mg, 6xxx-Mg-Si, 7xxx-Zn and 8xxx-others, and 9xxx-Unused series while the cast Al series are 1xx.x-Al, 2xx.x-Cu, 3xx.x-Si, Cu and/or Mg, 4xx.x-Si, 5xx.x-Mg, 7xx.x-Zn, 8xx.x-Sn, 9xx.x-Others, and 6xx.x-Unused series.

1.3 Al-Si alloys

According to the weight percentage of the silicon content, the Al-Si alloy can be classified in the following three different categories:

1. Hypoeutectic Al-Si alloy (Si < 11%)
2. Eutectic Al-Si alloy (Si = 11-13%)
3. Hypereutectic Al-Si alloy (Si > 13%)

The major applications of Al-Si alloy are as follows:

a) Automotive applications: Pistons, wheels, pump and compressor bodies, Brake cylinders etc.

b) Aerospace applications: Pistons, Aircraft pylons, Canopies, Flaps, Fittings.

c) Electrical applications: Transmission towers, Wire and cable, Electrical connectors, Electrical appliances.

d) Household applications: Consumer durables, Packaging foils.

Generally, different casting techniques are used for the manufacturing of various components of Al-Si alloy. However, the cast products show common casting defects such as shrinkage, air entrapment, and porosity. During solidification, the hypoeutectic composition of the cast products have liquid segregation, dendritic microstructure and needle shaped eutectic Si particles, whereas coarse primary silicon particles usually occur in hypereutectic composition of Al-Si alloys. Such microstructural features deteriorate the mechanical and tribological properties of these alloys (Prasad et al., 1998). Therefore, the coarse dendritic structures and primary Si particles must be changed to improve the properties of the alloy. Mechanical and metallurgical properties of the Al-Si alloy depend on the shape and size of the silicon particles and their distribution in the Al matrix. The refined morphology with a uniform dispersion of the silicon particles improve the mechanical properties of the alloy (Qi et al., 2018). Different grain refiners and/or modifiers have been used to refine the grain structure of the Al-Si alloys (Liu et al., 2014). However, the improvement in tribo-mechancial properties has been found to be insignificant.

Since most of the engineering components are subjected to high fluctuating tensile/compressive loads, severe friction and abrasion, which result in the premature failure of the components. Under such working conditions, the component demands sufficient strength to withstand against catastrophic failure. Casting techniques are unable to produce such components with adequate strength and toughness. However, the bulk material processing techniques such as forging, extrusion, rolling, etc have been found to be the most convenient way to improve the morphology of the cast Al-Si alloys and in turn, enhance the mechanical and tribological properties. The improvement in such properties is attributed to the refinement in microstructural features which leads to strong interface bonding between the second phase particles and the Al matrix (Wu and Liao, 2013; Lee and Kim, 2016). Therefore, bulk processing is recommended for manufacturing of Al-Si alloys component with improved tribo-mechanical properties. The bulk processing has major advantages such as refined microstructural features, excellent mechanical properties and close tolerance of the product.

1.4 Literature review

This section provides an overview of the literature review on industrial processing and characterization of the Al-Si alloys. Authors have used different techniques to process

Al-Si alloys and synthesize their microstructural features, mechanical properties, and tribological characteristics. A brief account of the literature available on processing and characterization of different Al-Si alloys is presented below in chronological order.

1.4.1 Bulk Processing of Al-Si alloys

Bulk processing techniques such as forging, extrusion, and rolling are being used to produce Al-Si alloy components. The bulk processing may be performed under following plastic deformation conditions:

a) Hot or cold working temperatures, and

b) Slow or high speed deformation rate, and

c) Lubricated or unlubricated interfacial frictional conditions, and

d) Restricted or unrestricted metal flow

Generally, cold bulk processing is performed below recrystallization temperature or room temperature, whereas hot bulk processing is done above the recrystallization temperature. In cold bulk processing, material strengthens due to dislocation movements occurred in the lattice crystal structure during plastic deformation. Therefore, strength and hardness of the material increases during cold bulk processing. The deformation above the recrystallization temperature allows the material to be free from strain hardening because the materials recrystallize during bulk processing. Due to this, ductility and yield strength improved significantly, whereas the hardness gets reduced during bulk processing (Handbook, 1988). Therefore, hot processing produces desired shape and size of product with superior mechanical and metallurgical properties at relatively lower applied load.

A considerable amount of research work has been done on various aspects of the bulk processing of Al-Si alloys. Mostly the investigators have performed experiments on forging, extrusion and rolling of Al-Si alloys.

1.4.2 Processing of Al-Si alloys through forging operation

Kang et al. (1999) studied the compression behavior of semi-solid ALTHIX (A356) alloy. The results reveal that the macro-separation occurred between solid and liquid region, and it increases further with increase in the die velocity for different solid fractions and working temperatures. It was also observed that morphological features show structure densification due to deformation of the solid grains at the center while the outermost section contains porosity due to macro-segregation.

Kang and Jung (2001a) designed die-set to produce scroll shaped components for ALTHIX 86S Al alloy using the thixoforming process to avoid liquid segregation. They used finite element method (FEM) to optimize the material flow behavior against die pressing velocity to completely fill the die cavity. They concluded that defect free thixoformed product can be obtained by varying the pressing velocity.

Kang and Jung (2001b) also examined the optimal deformation of semi-solid A357, 86S, and A390 aluminum alloys for net shape product by using parallel plate compression. The results show that defect free product obtained through multistage compression by varying the strain rate as compared with applied lower or higher strain rate. They also reported that defect free product obtained in a semisolid compression forming by increasing stress and strain rate.

Seo at el. (2002) studied the deformation behavior of the semi-solid ALTHIX (A356) alloy during forging process and optimal processing conditions. The cracks were observed on the equatorial free surfaces and they were more severe at the outermost of the compressed samples. It occurred during compression due to variation in the preform diameter and/or height. The microstructure of the outermost surface contains porosity due to non-uniform dispersion of the solid grain and liquid phase during compression. The amount of fine grain increases with an increase in the strain rate during compression.

Kang et al. (2005) performed thixoforming of semi-solid hypoeutectic (A357, and A319 Al alloy) and hypereutectic Al-Si alloy (A390 Al alloy) at different applied pressure. The results show that thixoforming produces uniform dispersion of globular microstructure in hypoeutectic Al-Si alloys, while the presence of fine size primary silicon in hypereutectic composition at different applied pressure (110, 140, and 170MPa).

Rajabi et al. (2009) studied the effect of rapid solidification and alloying element during melt spinning and gas atomized powder followed by hot pressing and hot consolidation of Al–20Si–5Fe–2X (where X=Cu, Ni and Cr) alloys respectively. The results reveal that hot pressing changes the microstructure of both the processed alloy. The hot pressed samples show significant improvement in hardness as compared to conventionally cast alloy.

Haghshenas et al. (2009) investigated microstructural features and mechanical properties of the thixocast Al-7Si- 0.4Mg alloy under cold compression and subsequent heat treatment for different holding time. The results reveal that cold deformation destroyed original cast structure in which α-Al matrix deformed plastically, however hard eutectic silicon cannot sustain such a deformation load and broken down during the process. Cold deformation causes strengthening alloy due to strain hardening as results of dislocation pile-up and interaction with each other. Hardness of the material increases as increase in the percentage deformation due to strain hardening during cold compression.

Murali and Yong (2010) used liquid forging process to manufacture the thin structures of Al-10wt%Si-3wt%Cu alloy. The results depict that liquid forging was successful to produced thin structures up to 0.2 mm thickness, while below this thickness the structures got fractured during processing. The microstructural studies reveal that the refined grain structure was obtained with no porosity formation during liquid forging. The results also show the segregation of silicon during process and it increases with decrease in the plate thickness. It may be due to lower temperature of die and punch which causes segregation of Si particles.

Mallapur et al. (2011) investigated microstructural refinement of forged A356 alloy and its effect on mechanical properties through grain refiner and modifier. Microstructural refinement was observed in the forged samples as compared with as-cast alloy, it may be due to fragmentation and uniform dispersion of the eutectic Si particles in the α-Al matrix. Such improvement in microstructural features significantly enhanced the tensile properties and hardness of the forged alloy as compared with as-cast alloy.

He et al. (2012) investigated hot deformation behavior of Al–17.5Si–4.5Cu–1Zn–0.7Mg–0.5Ni alloy and its post processing through aging. The results reveal that the tensile properties of hot deformed and aged test sample depends on the aging temperature and time. The enhancement in UTS was attributed to the formation of nano sized rod-shaped and lath-shaped precipitates at 150°C which are coherent with the Al-matrix and strengthen the material, while slightly coarser plate-shaped precipitates formed at 180°C which lowers the UTS.

Goudar et al. (2013) performed spray forming and subsequent hot pressing of Al–30Mg2Si–2Cu alloy to study the microstructural changes and its effect on wear behavior during dry sliding condition. Results reveal that hot pressing of alloy significantly refined the microstructural features, while refined particles coarsened due to solution treatment which were further refined when subjected to aging. Significant improvement in hardness of the alloy during processing enhanced its tribological properties during dry sliding.

Wu et al. (2014) performed liquid die forging of hypereutectic Al-Si alloy and evaluates its microstructural features and mechanical properties. The results reveal that microstructural refinement and grain distribution were depended on the applied pressure, they were greater for higher applied pressure. Due to this, the fracture strength and elongation of the processed alloy were increased significantly during liquid die forging.

Cai et al. (2015) processed gas atomized Al–(22–50 wt.%) Si powder through hot pressing at 400°C and evaluated its microstructural features and mechanical properties. The results reveal that hot pressing improves the Si grain structure in the gas atomized Al-Si alloys compact, and shows uniformly dispersed pore-free microstructure. Such refinement in Si morphology significantly enhanced the mechanical properties such as tensile strength, coefficient of thermal expansion (CTE) and hardness of the processed alloy, and it was higher with high Si wt% in the composition.

Shaha et al. (2015) studied the effect of micro-addition of Ti, V and Zr contents on deformation characteristics of the Al–7Si–1Cu–0.5Mg (wt.%) alloy during monotonic and cyclic tensile and compression tests. The size of the α-Al dendrites reduced, eutectic Si grains were partially dissolved, and intermetallic compounds were dissolved or partially dissolved during T6 heat treatment. Addition of Ti, V and Zr content in the alloy enhanced its tensile strength and fracture stain due to precipitation strengthening during T6 heat treatment.

1.4.3 Processing of Al-Si alloys through extrusion operation

Gupta and Ling (1999) investigated the effect of disintegrated melt deposition (DMD) process of Al-Si alloys with 7, 10, and 19 wt % Si followed by extrusion on microstructural features and mechanical behavior of the material. The results reveal the variation in volume fraction of porosity with Si content and it was higher with greater silicon content i.e. Al-19Si. Microstructural refinement was observed in the Al-19Si alloy during extrusion process which consequently improved the tensile strength and hardness of the extruded alloy by 49% and 36% as compared to as-cast alloy.

Wang et al. (2003) synthesized Al–20Si–5Fe–3Cu–1Mg alloy through the spray deposition techniques followed by extrusion process with 10:1 reduction ratio at 400°C and T6 heat treated. The microstructural refinement observed during processing due to fracture and split of the Si particles into fine particles and homogeneously distributed in the matrix due to applied extrusion pressure. Such refinement in microstructural features enhanced the tensile properties of the extruded alloy followed by T6 heat treatment.

Baiqing et al. (2003) performed a spray forming of complex hypereutectic Al-Si alloy with varying gas to melting metal ratio followed by hot extrusion, and its effect on the Si particles morphology. The results reveal that microstructural refinement occurred in the extruded alloy due to broken coarse primary Si phase into the fine size and uniform dispersion in the Al-matrix during extrusion. Therefore, the extrusion process was extensively used to modify the primary Si morphology.

Ahlatci (2008) studied tribo-mechanical properties and corrosion behavior of Al-12Si-XMg (where X= 0, 5, 10, and 20wt.%) with successive extrusion at 573 K temperature and 1.6 reduction ratio. The results reveal the formation of Mg_2Si intermetallic phase during solidification with varying size from fine to coarse polyhedral shaped particles. The tribological properties of the alloy depend on the hardness value, and the material shows the lowest wear resistance having a very low amount of Mg wt.%. However, corrosion resistance decreased with increase the Mg content in the alloy, it may be due to cathodic behavior of Mg_2Si particles in a galvanic cell.

Cui et al. (2010) studied spray forming of hypereutectic Al-Si alloy with varying Si content (18, 25, and 35wt.%), and subsequently performed hot compression to analyze the deformation behavior of the compressed alloy. The results show that flow stress increased in the alloy having larger Si content (35 wt.%) at low compression temperature (300°C) due to strain hardening of the alloy. The microstructural refinement was attributed to the fracture of Si particle due to stress concentration during heavy extrusion pressure.

Haghdadi et al. (2013) investigated the effect of accumulative back extrusion (ABE) and isothermal heat treatment on microstructural properties of the A356 aluminum alloy. The cast structure which consists of α-Al and long eutectic Si phase was destroyed and refined due to applied stress during single pass ABE process. Coarsening of α-Al globule occurred due to diffusion take place between Al atoms.

Wang el al. (2014) have correlated the dynamic recrystallization and microstructural refinement during hot extrusion of Al-0.85Si-0.50Mg, Al-6.23Si-0.5Mg, and Al-12.3Si-0.6Mg alloys. It was found that the hot extrusion changed the morphology of the alloys in which primary α-Al dendrites changed into bands due to deformation. The refinement in the microstructural features of the extruded alloys attributed to dynamic recrystallization occurred during hot extrusion, and it was more matured and pronounced in the alloy with higher Si wt.%. The results reveal that the tensile strength of the material increased with increasing the Si wt.% in the alloy by reducing the ductility.

1.4.4 Processing of Al-Si alloys through rolling operation

Umezawa and Nagai (1999) used repeated thermomechanical treatment (RTMT) to study the deformation behavior of the Al-12.6 Si cast alloy. Results reveal that the billet splits into two parts during rolling at 293 K temperature in both 20 and 50% reduction. While rolling at an elevated temperature of 493 K shows defect free product at 20% reduction however, the degree of severity reduces as compared with 293 K temperature at 50% reduction. The refinement in microstructures occurred during RTMT process, the silicon particles fragmented into fine sized particles in spheroidized, which enhanced the tensile strength and elongation as compared to as-cast alloy.

Jamaati et al. (2011) investigated the effect of accumulative roll bonding (ARB) on microstructural features and mechanical properties of the A356 alloy. The results indicate considerable microstructural refinement during rolling due to fracture and fragmentation of acicular shaped eutectic Si particles, which were spheroidized, and uniformly dispersed in the α-Al matrix. As a consequent of uniformly refined Si particles, the tensile strength and hardness of the rolled alloy is enhanced significantly during ARB process.

It is evident from the above literature reviews that various authors have worked on the different bulk processing of the Al-Si alloys. The literature revealed that bulk-forming significantly improved the microstructural features, mechanical and tribological properties of the Al-Si alloys. However, very limited work is reported on the deformation behavior of the Al-Si alloy through the forging process using different die sets under various processing conditions. There is also a lack of work reported on the effect of processing temperatures, deformation speed, and their characterizations.

1.5 Dry sliding wear behavior of Al-Si alloys

Commercial pure aluminum is ductile in nature, and it is plastically deformed during sliding under application of the normal load. Due to this plastic deformation, it shows poor tribological characteristics. Therefore, plastic deformation and adhesion are the primary wear mechanisms in the pure Al and its alloys during dry sliding conditions (Kuo and Rigney., 1992; Talachi et al., 2011; Edalati et al., 2014). In the last few decades, the investigators have tried to improve the tribological characteristics of the Al and its alloys. These processes comprised of the addition of alloying elements or composite reinforcement during casting, or some other surface hardening techniques (Deuis et al., 1997; Bindumadhavan et al., 2001). It leads to significant improvement in strength and hardness properties, which enhances the wear resistance of the material.

Aluminum-silicon alloy exhibits superior tribological characteristics, and it is considerably enhanced with increase in silicon wt.% in the alloy. In Al-Si alloy, the presence of hard Si particles reduce the direct contact of the soft Al matrix to the counter face during sliding, which reduces the frictional heat generation. Frictional heat generation during sliding is responsible for the plastic deformation of the contacting surfaces, and it is more pronounced at high speed or load. There are numerous efforts have been made to improve the wear resistance of the Al-Si alloys through different techniques. However, actual prediction of the possible wear mechanisms is essential in any contacting surfaces and sub-surfaces to overcome the wear during sliding. The authors have reported that different wear mechanism acting in the Al-Si alloys during dry sliding conditions depend on the various process parameters such as material composition and physical properties, applied normal load and sliding velocities, surface roughness, test temperature, environmental conditions, etc. The material physical properties depend on the chemical compositions and their microstructural features. The literature reveals that addition of various alloying elements such Fe, Cu, Mg, Mn, etc. in the Al-Si alloy strengthen the material by formation of different hard intermetallic compounds, which subsequently improved the wear resistance of the alloys. They also confirmed that transformation of coarse microstructural features to finer ones reduces the wear rate during dry sliding conditions. This can be done by using metal forming as a manufacturing process of components or some other techniques such as severe plastic deformation (SPD) or various heat treatment cycles. Such techniques refined the microstructural features and uniform dispersion of the second phase particles. A brief literature review is presented on wear behavior of the Al-Si alloy by considering the effect of alloy elements, wt.% of Si, different metal forming processes, and SPD techniques.

Dwivedi (2006) observed effect of alloying elements on wear characteristics of cast Al-17Si and Al-17Si-0.8Ni-0.6Mg-1.2Cu-0.6Fe alloys under dry sliding condition. The results reveal that wear performance of the alloy significantly improved through the addition of alloying elements. It may be attributed to the formation of complex intermetallic compounds during solidification which is hard and thermally stable, enhanced the wear resistance of the alloys. The worn surfaces reveal that mild oxidative wear was responsible for the material loss during dry sliding.

Kucukomeroglu (2010) evaluated the wear characteristics of the equal-channel angular extrusion (ECAEed) Al-12Si alloy slides against AISI 1045 steel counter disc (56 RC) at dry condition. The results reveal that EAPEed alloy shows poor wear resistance during sliding as compared with as-cast alloy. It may be due to higher oxidative wear mechanism acting on the contacting surface and counterface as a result of tribochemical response as compared with as-cast alloy.

Raju et al. (2011) investigated wear behavior of the as-cast and hot pressed spray formed Al-12Si under dry sliding condition. The hot pressed alloy shows superior wear resistance as compared with as-cast alloy due to improvement in hardness of the material during processing. The results also indicate that wear rate and friction coefficient of the alloy in both conditions was decreased when increased sliding velocity. It may due to less time available for growth and development of micro welds during sliding at high speed which reduces the mass loss and improves the wear resistance of the alloy.

Goudar et al. (2013) evaluated the effect of the alloying elements (5wt.% Cu and 4wt.% Fe) on wear characteristics of the spray formed and hot pressed hypereutectic Al-28Si alloy at dry sliding condition. The results reveal that spray formed and hot pressed alloy shows reduced wear rate and friction coefficient during dry sliding. Worn surfaces analysis reveal that as-cast material deformed plastically due to adhesion, and deeper grooves and plowed were formed due to abrasion. Abrasion and adhesion also dominant wear mechanism in the spray formed and processed alloys.

Gode et al. (2014) investigated microstructural, mechanical and wear properties of the extruded (EXTR), and subsequently high pressure torsion (HPT) processed Al-15Si-2.5Cu-0.5Mg alloy and its SiC particles reinforced composite. The results show that considerable improvement in tribological performance of the HPT processed test samples as compared with EXTR processed. The worn out pin consists of smearing surfaces and scratches in the sliding direction was confirmed that abrasion is the dominant wear mechanism in the contacting surface.

The dry reciprocated sliding wear characteristics of as-cast, and high-pressure torsion (HPT) processed Al–7Si alloy plate rubbed through tungsten carbide ball (75 HRC) at room temperature was investigated by **El Aal and Kim (2014).** The experimental results reveal that wear resistance of the HPT processed alloy improved as compared to as-cast. The mass loss in the as-cast alloy during wear test was due to plastic deformation, oxidation, delamination, and adhesion, while adhesion and abrasion were the dominant wear mechanism in the HPT processed alloy.

The wear behavior of the thixoformed A319 Al alloy was evaluated by **Alhawari et al. (2015)** under dry sliding conditions at room temperature. Results reveal that thixoformed alloy shows reduced material loss during dry sliding than conventionally cast alloy. The results also exhibit severity of the wear rate was higher at higher applied load, due to which the material deformed plastically during dry sliding. Therefore, the material worn out at low load due to abrasion and adhesion, while adhesion was the leading wear mechanism at higher applied load.

Chong et al. (2016) studied the tribological behavior of hypereutectic Al−17Si−2Cu−1Ni alloys with varying Fe content at the dry sliding condition at room temperature. The formation of fine size complex Fe-rich intermetallic phases during solidification reduces the mass loss of the alloy during sliding. The worn surface analysis reveals that oxidation was the dominant wear mechanism at lower applied load, while at higher load the material worn out in the form of wear debris due to oxidation and delamination during sliding.

Singh et al. (2016) studied the wear characteristic of the as-cast alloy and friction stir processed (FSPed) A356 alloy through dry metallic (EN31 hardened steel) and abrasive sliding (SiC abrasive) condition at room temperature. Due to higher roughness of the SiC abrasive counter sheet the alloy shows greater wear rate at low applied load (1 kg.) when it slides against abrasive counter sheet as compared to metallic disc even at greater applied load (3 kg.). Adhesion and abrasion were the dominant wear mechanism in the metallic medium, while wear occurred during abrasive medium was due to micro-cutting. **Akbari et al. (2018)** investigated wear behavior of the friction stir processed (FSP) A356 Al-Si alloy under dry sliding conditions. Significant improvement occurred in the hardness of the alloy during FSP process, which subsequently enhanced the wear resistance of the alloy. Worn surfaces comprise of plowed grooves and wear pits which confirmed that abrasion and delamination were the dominant mechanisms for wear.

The above literature reviews confirmed that adhesion and abrasion are the dominant wear mechanism in the Al-Si alloys. The occurrence of wear mechanisms depends on the applied loading conditions, sliding speed, material mechanical properties.

1.6 Motivation of the present research work

The engineering components of Al-Si alloys produced through casting techniques possess relatively low tribo-mechanical properties. In order to improve such properties different heat treatment cycles or modification techniques were used, which further increased the production time and power consumption, and ultimately increased the cost of the components. However, components manufactured through bulk-forming techniques show excellent tribo-mechanical properties at minimum production time and power consumption, which in turn reduce the cost of the components. Obviously, the above issues were the prime motivating factors to undertake the present research work.

1.7 Formulation of the work

The above literature reviews reveal that numerous investigations have been performed to evaluate the microstructural features, and tribo-mechanical properties of the Al-Si alloys processed through different techniques. Unfortunately, there is no systematic attempt has been made to study the bulk deformation behavior of the alloys. These bulk-forming techniques have many advantages, nevertheless, the processing of complex Al-Si alloys containing Cu and Fe metal through the metal forming route is very difficult due to the presence of hard and brittle silicon particles along with various complex intermetallic compounds. Such second phase particles nucleate cracks in the Al matrix during deformation, which in turn fracture and surface defects are formed in the final products and impairs its tribo-mechanical properties. Therefore, it is highly essential to modify such detrimental microstructural constituents into fine, and their uniform dispersion in the Al matrix which enhances the tribo-mechanical properties of the alloy and fulfill the industrial demands. Various processing parameters such as die set-ups, temperature, deformation ratio, lubrication, etc. during bulk-forming significantly affects the microstructural features and tribo-mechanical properties of the formed product. Therefore, systematic investigations are necessary to study the effect of the aforementioned processing parameter during bulk-forming of complex Al-Si alloy.

1.8 Objective of the thesis

The objective of the present investigations is to study the processing and characterization of Al-Si alloys through bulk forming techniques. In the present work impression die and converging die compression of complex Al-18Si-2.5Cu-0.6Fe alloy (hypereutectic), Al-11Si-2.5Cu-0.6Fe alloy (eutectic), and Al-7.4Si-2.5Cu-0.6Fe alloy (hypoeutectic) have been performed at elevated temperatures to study the following objectives:

1.8.1 To study the feasibilities of the bulk processing of the complex Al-Si alloys during open-die and impression-die compression as well as converging-die compression at different processing temperatures.

1.8.2 To examine the effect of bulk processing temperatures on microstructural characteristics, and mechanical properties of the material.

1.8.3 To study the tribological behavior of the bulk processed Al-Si alloys.

1.9 Organization of the thesis

The thesis has been structured in the following sections, which includes:

Chapter 1: Introduction and Literatures Review

Chapter 2: Experimental Work

Chapter 3: Deformation Behavior and Tribo-Mechanical Properties of the Complex Hypereutectic Al-18Si-2.5Cu-0.6Fe alloy during forging

Chapter 4: Deformation Behavior and Tribo-Mechanical Properties of the Complex Eutectic Al-11Si-2.5Cu-0.6Fe alloy during Forging

Chapter 5: Deformation Behavior and Tribo-Mechanical Properties of the Complex Hypoeutectic Al-7.4Si-2.5Cu-0.6Fe alloy during Forging

Chapter 6: Comparative Studies of the Bulk Processed Complex Al-Si Alloys

Chapter 7: Conclusions and Scope for Future Work

References

The next Chapter 2 is on experimental work related to the present research investigations.