Study on Influences of Addition of Alloying Elements on Properties of Aluminium – Silicon Alloys: A Review

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ABSTRACT

Now a day's aluminum and aluminum alloys are widely used in automotive industries. These are light weight (density of about 2.7g/cc), having good malleability and formability, high corrosion resistance and high electrical and thermal conductivity. High machinability and workability of aluminum alloys are prone to porosity due to gases dissolved during melting processes. However, in the engineering application pure aluminum and its alloys still have some problems such as relatively low strength, unstable mechanical properties. The microstructure can be modified and mechanical properties can be improved by alloying, cold working and heat treatment in this regards, this paper reports the influences of some alloying elements on the microstructures and mechanical properties of Aluminum-silicon alloys and its composites.

Keywords - **Aluminium alloy, aluminium- silicon alloy, aluminium- silicon-titanium alloy, tribological properties.**

1. Introduction

Aluminium and aluminium alloy are gaining huge industrial significance because of their outstanding combination of mechanical, physical and tribological properties over the base alloys[1]. These properties include high specific strength, high wear and seizure resistance, high stiffness, better high temperature strength, controlled thermal expansion coefficient and improved damping capacity. These properties obtained through addition of alloy elements, cold working and heat treatment[2]. Alloying elements are selected based on their effects and suitability. The alloying elements may be classified as major and minor elements, microstructure modifiers or impurities, however the impurity elements in some alloys could be major elements in others[3]. Now a days the aluminium-silicon alloys found many industrial application. In this paper the influences of alloying Such as Major elements (Ti, Mg, Ce, Co, Na), Minor elements (Ni, Sn) ,and Impurity elements (Fe, Zn) on microstructures and tribological properties of aluminium-silicon alloys are reviewed.

2. Literature Review

A number of research paper has been studied which deals with the tribological investigated light weight materials like Aluminium- Silicon based alloy for piston alloy application. The findings of those papers have been presented here.

Francis Uchenna et al studied the effect of parameters on dry sliding wear characteristics of Al-Si alloys. Aluminium-silicon alloys containing 7%, 12% and 14% weight of silicon were synthesized using casting method. Dry sliding wear characteristics of sample were studied against a hardened carbon steel (Fe-2.3%Cr-0.9%C) using a pin-on-disc. Observations were recorded keeping two parameters (sliding distance, sliding speed and load) constant against wear at room temperature. Micro structural characterization was done using optical microscope (OM) and scanning electron microscope (SEM). Hardness and wear characteristics of different samples have shown near uniform behaviour. The wear rate decreased when the percentage of silicon increases. Wear was observed to increase at higher applied load, higher sliding speed and higher sliding distance. The wear characteristics of Al-14%Si was observed superior to those of Al-7%Si and Al-12%Si due to the degree of refinement of their eutectic silicon. The variation of silicon in Al-Si led to more degree of refinement of the eutectic silicon as the silicon content of the alloy increased beyond the eutectic composition. The amount of primary silicon increased with the increase in silicon amount in the cast. Hardness of the Al-Si alloy increased with the increase in amount of silicon present. The wear rate decreased when the percentage of silicon was increased. Wear was observed to increase at higher applied load and at higher sliding speed. Effect of load and sliding speed are more pronounced on the wear of the Al-Si alloys than sliding distance[5].

Riyadh A et al studied the effect of load and speed on sliding friction coefficient and performance tribology of aluminum–silicon casting alloy was evaluated using a pin-on-disc with three different loads (10, 20, and 30 N) at three speeds (200, 300, and 400 r/min) and relative humidity of 70%. Factors and conditions that had significant effect were identified. Experiments showed that the load and the speed affect the coefficient of friction and wear rate of the alloy. The results showed that the wear rate increased with increasing load and decreased with increasing sliding distance, whereas the friction coefficient decreased with increasing sliding speed before a stable state was reached. The friction coefficient also decreased with increasing load. The load and the sliding speed affect the amount of friction force. The wear rate significantly increases when the load increases. On the other hand, small coefficient of friction values, together with increase in sliding speed, loading, and sliding over long distances, reduce wear rate. Thus, maintaining appropriate sliding speed and normal load levels can reduce frictional force and wear and improve the mechanical processes[6].

Muna K. Abbass studied the effect of cadmium addition on microstructure and wear behavior of the alloy (Al-12%Si) under dry sliding conditions. Wear behavior was studied by using the Pin-On-Disc technique under different conditions at applied loads 5-20 N, at constant sliding speed and in constant time. The steel disc hardness was 35HRc. All alloys were prepared with different percentages of cadmium (1.0, 2.0, 3.0) wt%. Also the base alloy was prepared by melting and pouring the molten metal in a metallic mold. It was found that the cadmium addition to Al-Si matrix decreases the wear rate and improves the wear properties for alloys containing - Cd under loads above 10N. It was also found that the alloy Al-12%Si containing 3%Cd is the best alloy in wear resistance and friction coefficient. This is due to presence of the Cd-phase as cuboids or hard particles distributed in a eutectic matrix which reduces the friction coefficient at high loads (20N). Modification and grain refinement in the microstructure of Al-Si alloy have been achieved by the presence of cadmium particles in the alloy matrix.The wear behavior of base alloy A1-12%Si changes from mild wear (oxidative wear) at low loads 5-10 N to metallic wear at high loads 10-20 N. The cadmium added to alloy Al-12%Si changes the wear behavior at higher loads than 5-10 N. The alloy A1-12 % Si containing 3% Cd shows the highest wear resistance in comparison with other alloys at a high load 20 N. The cadmium added to alloy Al-12 % Si reduces the friction coefficient at high loads. The addition of cadmium at different ratios leads to an increase in the hardness of the aluminum silicon based alloy[7].

M. Zeren et al reported that the existence and morphology of intermetallic particles in Al–Si–*x*Ti cast alloys. Near eutectic Al–Si alloys with 0, 0?1, 1, 2, and 5% Ti have been utilised for this purpose. Metallographic observations were made by the combination of an optical microscope and a scanning electron microscope. Wear tests were performed in a pin on disc tribometer under dry sliding conditions. The addition of Ti to the Al–Si alloys led to the precipitation of TiAlSi intermetallic phase. By increasing Ti content, hardness increases due to increasing volume fraction of relatively hard intermetallics. The conclusions based on the experimental results are as follows. Ti based intermetallics can have different morphologies (flakes and petals) depending on the Ti content, other alloying elements and the thermal history of alloy. Ti based intermetallic phases in Al alloys also have different chemical compositions depending on other alloying elements and cooling rate of the alloy. The petal-like particles were found in the cast Al–Si–1Ti microstructure. The flake-like particles were found in the cast Al–Si–2Ti and Al–Si–5Ti microstructures. The alloys have maximum 0?2% vanadium, but no effect of vanadium was reported in microstructural investigations. To understand influence of vanadium further investigations are required. The increase in the Ti content increases the hardness of the alloys by increasing the volume of hard TiAlSi intermetallics. The hardness increases from 841 HV to 1454 HV with addition of 5 wt-%Ti. The micro structural characteristics, namely, the morphology and size of the hard second phases greatly affect the sliding wear properties of the alloys. It was found that the weight loss of the as cast Al– Si–xTi alloys decreased with increasing Ti content up to 1% Ti. This may be due to the morphology and distribution of the hard TiAlSi intermetallic particles. It was found that the coefficient of friction of the as cast Al–Si–xTi alloys increased with increasing Ti content. The worn surface analyses show that the flake-like intermetallic particles causes the increase on wear rates. If the morphology of the intermetallics in high Ti including alloys can be modified to petal-like shapes, the wear resistance of the alloys will be enhanced. More research work is necessary to understand and control the morphologies and growth properties of TiAlSi intermetallics[8].

N. Saheb et al studied the influence of Ti addition (up to 4 wt.%) on wear behavior of as-cast and heat-treated Al–12 wt.% Si eutectic alloy prepared by rapid cooling has been investigated in dry sliding against a steel counterface using a pin-on-disk apparatus. Worn surfaces and wear debris were examined and analyzed by scanning electron microscopy (SEM), energy dispersive X-ray spectroscopy (EDS), and X-ray diffraction (XRD). The addition of Ti to the binary Al–Si alloy led to the precipitation of Al3Ti phase. Among the Ti-containing alloys, the increase in Ti content improved wear resistance of both as-cast and heat-treated alloys. However, these alloys displayed higher wear rates, thus lower wear resistance, compared with the Al–Si binary alloy. The addition of Ti to Al–Si eutectic alloy resulted in the precipitation of the intermetallic compound Al3Ti phase, which induced an increase in the microhardness of the binary alloy. Among the Ti-containing alloys, the increase in Ti content improved their wear resistance as a result of increase in the microhardness due to the presence of relatively hard-phase Al3Ti. However, these alloys showed higher wear rates (thus lower wear resistance) compared with the binary alloy due to the tendency for embrittlement and microcracking brought about by Al3Ti particles. Heat treatment of the Ti-containing alloys at 200◦C for 6 h improved further their wear resistance[9].

A. S. Anasyida et al studied that the effect of cerium addition on wear behaviour of as-cast Al-4Si-4Mg alloys has been studied. Dry sliding wear tests were performed against a hardened carbon steel (Fe-2.3%Cr-0.9%C) using a pin-on-disc configuration with fixed sliding speed of 1 m/s and a range of load 10 N, 30 N and 50 N at room temperature ($25^{o}C$). Morphologies of both worn surfaces and collected debris were characterised by a scanning electron microscope (SEM) equipped with an energy dispersive X-ray spectrometer (EDX). It was revealed that 1 - 5 wt% of cerium addition resulted in the formation of intermetallic phase Al-Ce and Al-Si-Ce. The increase of cerium content in the alloy led to higher wear resistance behaviour for as-cast alloys. Formation of craters and localised plastic deformation were observed on the worn surface of the alloys, resulting fine particulate and sheet-like wear debris. The change in morphology of the wear debris was also found consistent with the change in worn surface appearance. The addition of cerium to Al-4Si-4Mg leads to the precipitation of intermetallic compound needle-like shape Al-Ce and Al-Si-Ce phase. The increase of cerium up to 5wt% improved wear resistance and lowered the friction coefficient of the as-cast alloy. The severity of abrasive and delamination wear mechanisms observed on the worn surface was found to be consistent with the cerium content in the alloys. Formation of craters and severe localised plastic deformation were observed on the worn surface of alloys with higher cerium content, which produces fine particulate and flakes wear debris[10].

Dr. Adnan Ibrahim Mohammed et al conducted demonstration of the effect of Na addition to the microstructure and wear rate of hypereutectic Al-14 wt% Si alloy was carried out. It is found that the addition of Na has an important effect on shifting the eutectic composition of Al-Si alloys from approximately 12 wt% to 14 wt% Si; shifting the unmodified alloy from hypereutectic to eutectic alloys for the modified alloys. The modified alloys have a eutectic composition with fine needle at lower Na content (0.05%). Increasing the percentage of Na to 0.12 wt% resulted in producing a lamellar Si structure compared with acicular structure for unmodified alloy. The wear rate of modified alloys is lower than the hypereutectic alloy. Wear rates observed were in the range of 10-9 to 10-11 which is fully identified in the mild wear rate regime. Addition of sodium to Al-14 wt% Si changed considerably the morphology of Si from acicular to fine needle at low Na addition to lamellar at high Na addition. The percentage of porosity increased with increasing the Na addition. The unmodified alloy with hypereutectic composition has changed to eutectic structure for modified alloys. Addition of Na has a considerable improvement in wear resistance compared with unmodified Al-14 wt% Si alloy[11].

Malek Ali et al in their study presented the mechanical properties of Al–12% Si matrix composite reinforced (which can used in light devices and energy storage) by various amounts of Titanium Nitride (TiN) particles. Macrostructural studies have shown near uniform distribution of TiN particles in the matrix. The mechanical properties such as hardness and wear resistance are observed to be increased considerably compared to the matrix composite. The wear behaviour was investigated using a pin-on-disc wear testing machine with varying parameters such as normal load, reinforcement's percentage and track velocity. The results suggested that the reinforced Al-12Si matrix composites showed significant improvement in their wear resistance accordingly with increasing the reinforcement's percentage at different conditions. The microstructural study of the composites before wear test showed uniform distribution through the cross-section of the specimens and finer surfaces than matrix composite after wear test. Fabricating Al-Si eutectic alloys reinforced by TiN ceramic particles using PM technique was done successfully. TiN reinforced samples have shown higher wear resistance than unreinforced samples. Similarly, when the speed increases with different applied loads, TiN reinforced samples have exhibited higher wear resistance than the rest. Where, after adding 15% of TiN particles it showed that the loss wear in average has been decreased about 49.5% compared to the base sample[12].

A. Apasi et al studied the wear behaviour of aluminium alloy (Al-Si-Fe) reinforced with coconut shell ash particles (CSAp) fabricated by stir casting process was investigated. The wear and frictional properties of the metal matrix composites was studied by performing dry sliding wear test using a pin-on-disc wear tester by varying the applied load from 10-50 N, speed 2.0 m/s and sliding distance 4000 m. The morphology of the worn out surface was determined by scanning electron microscope (SEM). The results show that the coefficient of friction increases with increasing load for the Al-Si-Fe alloy and the composites containing CSAp. It is observed that, as the applied load increases, the wear rate also increases but decreased with CSAp addition. This is because, whenever applied load increases, the friction at the contact surface of the material and rotating disc obviously increases. Hence, incorporation of the coconut shell particles in the Al-Si-Fe alloy matrix as reinforcement increases the wear resistance of the material. From they concluded that the presence of the coconut shell ash particles in the matrix alloy results in a much smaller grain size in the cast composites compared to the matrix alloy. The hardness values of the developed composites increased with an increasing percentage of coconut shell ash particle additions. The coefficient of friction increases with increasing load for the Al-Si-Fe alloy and the composites containing CSAp. The wear mechanism reported was oxidation at lower loads and adhesion and delamination at higher load. It is observed that, as the applied load increases, the wear rate also increases. This is because, whenever applied load increases, the friction at the contact surface of the material and rotating disc obviously increases. The incorporation of the coconut shell particles in the Al-Si-Fe alloy matrix as a reinforcement increases the wear resistance of the material[13].

Amro M. AI-Qutub et al studied the dry wear behavior of $A1_20_3$/6061 Aluminum particulate composite under different sliding speeds and applied load using pin-on- disk tribometer at room temperature. Three grades of the submicron particle composites containing 10, 20, and 30 vol.% $A1_20_3$ were tested. The results illustrate that higher load and higher concentration of $A1_20_3$ particles lead to higher wear rates. For 10 and 20% $A1_20_3$ concentrations, the wear rate decreases with increasing sliding speed, while it increases for 30% $A1_20_3$. The surface morphologies of the worn composites indicate that at lower sliding speeds abrasion is dominant, while at higher sliding speeds delamination and adhesion increases. Results also indicate that the friction coefficient between the composite and the mating steel surface decreases with increasing sliding speed to a steady state. A pin-on-disk tribometer was used to perform dry wear tests for three grades of 6061 Aluminum composites containing 10, 20, and 30 vol.% AI20^ dispersions- Applied load (20 and 30 N) and sliding speeds (0.25, 0 .5, 1, and 1.5 m/s) were varied to investigate effects of particles concentration on the wear and friction mechanism. The results indicated that higher concentration of $A1_20_3$ increases wear rate of the composites, primarily due to the increased abrasive wear on the steel counter face. In addition, wear rates increase with applied load for all the composites regardless of sliding speed. On the other hand, the composites containing 10 and 20 vol.% $A1_20_3$ exhibit a decrease in wear rates with increasing sliding speeds. SEM results indicate increased delamination and adhesion wear with increasing sliding speed . It was also found that at low sliding speeds abrasive wear is the dominant wear mechanism EDAX analysis revealed that the transfer of iron from the counter disk to the composite is enhanced at lower speeds (abrasive wear). Friction coefficient between the composites and the mating steel surface marginally decreases to a constant level at higher speeds. Concentration of $A1_20_3$ has negligible effect on friction coefficient of the composite[14].

S.Srivastava et al investigated the tribological properties of Al-Sn-based alloy with different amount of graphite at different normal loads and sliding speed. A modified impeller mixing coupled with chill casting technique was used for the preparation of immiscible alloys. In this paper Al-Sn binary alloys was chosen for this study. This binary system shows the miscibility gap at different concentration and temperature. Graphite was chosen as reinforcing element which was reinforced in the Al-Sn matrix. The graphite content in the composite varied from 1.6 to 8.4 wt%. The presence of graphite in the matrix not only improves the mechanical properties but also improve the tribological properties due to lubricating action. The ductility of composite materials showed the adverse effect with increase of the graphite content in the matrix. Pin-on-disc sliding wear tests were conducted in an ambient condition to examine the tribological behavior of the aluminum-based graphite composite. The experiment was commenced at different sliding distance, speed and using normal load. Having finished the tests, the weight losses of the specimen were measured, wear and friction characteristics were calculated with respect to time, depth of wear track, sliding speed and bearing load. Friction coefficient and wear volume have shown large sensitivity to the applied normal load and the testing time (or sliding distance). The XRD and SEM analysis were used to analyze the wear debris and track. 1. The Al-Sn/Graphite composite is being prepared from liquid metallurgical methods. It can be observed from the present investigation that graphite could be successfully and uniformly distributed in aluminium-tin base matrix using impeller mixing chill casting technique. UTS, 0.2%PS and VHN increased with decreases with increases the volume fraction of the graphite in the matrix. The Al-6.3%Sn-8.4%Gr composite showed higher percentage of elongation while compared to Al-6.3%Sn-1.6%Gr. From the present investigation we have also observed that the ductility of composite increase with increase the percentage of graphite. The hardness is another affecting parameter which affects the rate of wear, decreases with increase the percentage of graphite in the matrix. At higher contents, a graphite agglomeration is presented, and this effect reduces the mechanical resistance. This variation is related to the graphite dispersion / agglomeration into aluminum alloy matrix. Wear rate with sliding distance shows almost a linear relationship for all combinations of loads and sliding velocities and composites. Wear rate increases continuously with applied load for all the sliding velocities and composites studied. Wear rate initially decreases with increase in sliding velocity attains a minima in wear rate and then increases with further increase in sliding velocity for all the loads and composites. Low loads and sliding velocities are dominated by oxidative debris whereas higher loads and sliding velocities are dominated by metallic debris. At low loads and sliding velocities wear track surface is largely covered with oxide layer and smooth in nature but at higher loads or sliding velocities surface is highly deformed with deep grooves and gross delamination occurs leading to larger wear rate. The coefficient of friction decreases with increase the graphite content in the matrix[15].

Amit Telang et al presented the effect of SiC particle reinforcement and further its heat treatment on Al alloy (ADC12) was studied in the application of automobile brake discs. ADC 12 was synthesized by stir casting process and its composite with silicon carbide (SiC) in weight percentage of 10% as the hard particle and its heat treated variety. The candidate materials have been compared with tests on a rig developed for testing of brake discs under variety of operating conditions. The brake disc test set-up is a facility developed for simulating on road brake disc operating conditions. The brake disc test procedure for performance evaluation has been developed and formulated based on the Bureau of Indian standards (IS-14664:1999) for the acceptability of results. For evaluation the performance has been compared with the conventional steel brake disc with an emphasis on brake torque. In general it is observed that the average brake torque for ADC12 alloy at all velocities and brake force is lower than steel. The brake torque of the composites is higher than steel, the addition of SiC particles increased material hardness and its brake torque. Heat treatment of the composite material further increased the brake torque. By observing the graphs following conclusions can be drawn-The apparatus simulates the actual operating condition of the brakes and provides an opportunity to the designer to evaluate the operating performance of the disc brakes in similar operating condition at the design stage more accurately before the brakes are put in actual operation. They found that the average brake torque for ADC 12-10 SiC is 14.3% better than steel where as ADC 12-10 SiC (HT) gives 54 % higher value than steel for the tested brake force and the coefficient of friction of ADC 12 is inferior by 40.5% on an average to the steel For the tested velocities the average brake torque for ADC 12-10 SiC is 16% better than steel where as ADC 12-10 SiC (HT) coefficient of friction gives 24% higher value than steel for the tested velocities, while the coefficient of friction of ADC 12 is inferior by 13% on an average to the steel. By observing the graphs it is visible that the performance of ADC 12-10 SiC and ADC 12-10 SiC (HT) brake discs is better than the steel and that of ADC 12 is inferior to the steel with respect to brake torque; comparison of the experimental test data agrees with such tests reported earlier in literature thus supporting the correctness of the system. The facility helps in comparative analysis of the different brakes material in the simulated condition which helps in selection of right material for a wide range of input parameter values[16].

Prasad, B K et al investigated effects of the shape and size of silicon particles on the sliding wear response of two Al-Si alloys, namely, LM13 and LM29. The LM13 alloy comprised 11.70 % Si, 1.02 % Cu, 1.50 % Ni, 1.08 % Mg, 0.70 % Fe, 0.80 % Mn, and remainder Al. The LM29 alloy contained 23.25 % Si, 0.80 % Cu, 1.10 % Ni, 1.21 % Mg, 0.71 % Fe, 0.61 % Mn, and remainder Al. Wear tests were conducted under the conditions of varying sliding speed and applied pressure. The alloys were also characterized for their microstructural features and mechanical properties. The presence of primary silicon particles in the alloy led to a higher hardness but lower tensile properties. Further, refinement in the size of the primary particles improved the mechanical properties of the alloy system. The wear behavior of the alloys was influenced by the presence of primary Si particles and was a function of their size. Samples with refined but identical micro constituents (e.g., pressure cast vs gravity cast LM29 in terms of the size of primary Si particles and dendritic arm spacing) exhibited better wear characteristics. Their overall effect was further controlled by the test conditions. It was observed that test conditions leading to the generation of an optimal degree of frictional heating offer the best wear resistance. This was attributed to the reduced microcracking tendency of the alloy system otherwise introduced by the Si particles. The reduced microcracking tendency in turn allows the Si phase to carry load more effectively and impart better thermal stability to the alloy system. This caused improved wear resistance under the circumstances. Further, the primary Si particles improved the wear resistance of the alloy system (e.g., gravity-cast LM29 vs gravity-cast LM13) under high operating temperature conditions. Additional thermal stability and protection offered to the matrix by the primary Si phase, under the conditions of reduced microcracking tendency, were the reasons for the improved wear characteristics of the alloy system. Conversely, a reverse effect was produced at low operating temperatures in view of the predominating microcracking tendency. The study suggests that shape, size, microcracking tendency, and thermal stability of different microconstituents greatly control the mechanical and tribological properties of these alloys. The extent of effective load transfer between the phases plays an important role in this regard. Further, the overall effect of these factors is significantly governed by the test conditions[17].

Pramila BN et al studied the effect of silicon content and pressure on the dry sliding wear of Al-Si alloys to clarify the question by reporting a statistical analysis of data obtained from factorially designed experiments conducted on a pin-on-disc machine in the pressure range 0.105–1.733 MPa and speed range 0.19–0.94 m/s. Under these conditions it was found that, in the range 4–24 wt.% Si, wear of binary unmodified alloys does not significantly differ between the alloys. However, it is significantly less than that corresponding to an alloy containing no silicon. The effect of pressure on wear rate was found to be linear and monotonie and, over the narrow range of speeds used, the wear rate was found to be unaffected by speed. The coefficient of friction was found to be insensitive to variations in silicon content, pressure and speed[18].

3. Conclusion

Alloying elements are selected based on their effect and Suitability. Silicon lowers the melting point and increase the fluidity (improve casting characteristics) of Aluminium. A moderate increase in strength is also provided by Silicon addition. Different alloying elements added to Al-Si alloy will improve its tribological properties. Some composites of Al-Si alloys are also improve its wear rates and friction properties. Further study of Al-Si alloy with Ti addition will planed to study effect of Ti addition on Friction and wear of Al-Si alloys in piston application.

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