# Effects of Additives on the Fatigue and Impact Properties of Recycled Al-Si Alloy wheels

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*Abstract*—Minor variations in alloy composition are the primary causes of casting rejects and occur even when the normal process conditions prevail. These variations impact significantly in microstructure and mechanical properties of aluminium alloy castings. Therefore, it is necessary to closely control the alloy composition and molten metal quality.

Al-Si alloys are light-weight structural materials which play an important role in vehicle weight reduction and improving fuel economy in automobile industry. Currently, 85 percent of aluminium castings are used in the automobile and aerospace industry due to the unique casting properties and mechanical strength.

Unfortunately however, Al-Si alloy castings are known to suffer from presence of iron that greatly undermine their mechanical properties such as impact energy and fatigue strength. Finding an innovative solution that reduces the effects of the presence of iron is an area of increased research interest.

In this paper, the effects of additive elements on the impact and fatigue strength of the aluminium alloy castings from wheels were investigated. The aluminium wheels were melted in an oil fired furnace and the metal poured into 4 kg ingots. A sample was collected in a carbide crucible, quenched and used to obtain the alloy chemistry. The ingots were re-melted at $750^{0}$C and poured into a sand mold. This procedure was repeated with variations of strontium, iron and manganese elements. The castings were then machined according to ASTM-E8 standards for the impact specimen and ASTM-E466-82 for the fatigue specimens.

The results depicted that Strontium addition increased both the fatigue life and impact strength of the alloy, while iron addition reduces. However, addition of manganese neutralized the detrimental effects of the iron.

*Keywords*—Aluminium alloy, Chemical additives, Fatigue strength, Impact energy, Casting .

## I. INTRODUCTION

ALUMINIUM silicon foundry alloys are the most commonly used alloys in the automotive, defense and aerospace industries mainly because of their high strength to weight ratios, better castability and good surface finish [1-2]. They also present good wear resistance and high welding characteristics. These alloys are also less prone to shrinkage, hot working and porosity defects as compared to other aluminium casting alloys such as Al-Cu alloys.

The effects of major alloying elements in aluminium are well known and documented. For instance, silicon is known to improve fluidity and reduce solidification shrinkage thus improving castability of silicon based aluminium alloys [3-4]. It also increases strength until the eutectic level percentage is reached. Copper in the range of between 2-5 percent provides optimum ductility whereas greater percentages increase hardness and strength mainly by precipitation hardening. Magnesium is also known to have a similar effect to copper. Zinc on the other hand makes it possible to achieve the maximum mechanical properties of aluminium alloys in the as-cast condition.

Strontium, antimony and sodium in trace amounts are known to cause modification of the microstructure of aluminium alloys from flat plate like or coarse lamellar structure to a fine fibrous rod-like structure or fine lamellar structure [1,5]. These structures are associated with improved mechanical properties but the benefits may be outweighed by porosity characteristics associated with modification.

Iron as an element is always present in Al-Si alloys as a carry-over of the alloy processing and handling. In concentrations of above 0.7wt percent iron has detrimental effects to mechanical properties and manganese is often used to counter its effects [6-7]. On occasions iron is deliberately added to Cu-Ni groups of alloys to increase their high temperature strength and in die-cast alloys, to reduce die soldering effects. For most Al alloys however, the detrimental effects outweigh the benefits and an effort is made to keep its level low.

Many repetitions of load can cause fracture in a material even though the maximum stress is far below the ultimate stress. Such a failure is called fatigue failure and may be catastrophic. In high iron containing alloys, $beta$-phase acts as the preferential site for crack propagation rather than silicon particles [8].

Impact strength is recommended on aviation and automobile parts that experience shock loads. Brittle failures result from stress raisers that originate from notches, poor surface finish or microstructure features (such as porosity, intermetallics, oxides and grain size)[9]. The impact test is useful in determining the ability of a material to absorb energy during deformation.

This study focuses on the effect iron, strontium and manganese as additives on fatigue and impact properties of recycled aluminium alloy.

## II. THE EXPERIMENTAL PROCESS

THE molten metal used in this study was obtained from scrap aluminium alloy wheels. These were melted in an oil fired furnace under a cover flux to prevent oxidation and hydrogen gas pickup. The melt was cast into ingots of approximately 4kg before a sample was obtained for chemical composition analysis. Four ingots of 4kg each were then re-

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melted in an electric muffle furnace and heated to a temperature of $750^0$ C and Al-10Sr master alloy added to achieve a 0.013wt percent strontium concentration. The melt was held for 10 minutes while gently stirring to ensure there was homogeneity in the entire mixture, degassed for 30 seconds using argon and cast into a silica-sand mould. This process was repeated with addition of iron to attain a melt composition of 0.4wt percent iron concentration and similarly with manganese to attain a concentration of 0.2wt percent. After solidification the moulds were broken and the castings machined according to ASTM-E8 standards for the impact specimen testing and ASTM-E466-82 specifications for the fatigue testing. The impact test was carried out using the Charpy impact testing machine with the following characteristics; hammer- 25.710 kg, arm length 0.65m and lift angle of $142^0$C. Fatigue tests were carried out using the fatigue testing machine model H7 at JKUAT metrology laboratory and set to a test speed of 2500 revolutions per minute. The microstructure specimens of about 25mm cube were wet ground, polished and etched. Using the optical microscope-Union ME-3295, photo micrographs were taken at different magnifications.

## III. RESULTS

### A. *Chemical analysis*

The results obtained from the chemical composition analysis are presented in the table I.

TABLE I
CHEMICAL COMPOSITION RESULTS

| **Alloy element** | Ca | Cu | Fe | Mg | Mn | Si | Sr | Al | The rest |
|---|---|---|---|---|---|---|---|---|---|
| **% Composition** | 0.07 | 0.01 | 0.18 | 0.11 | 0.02 | 7.49 | <0.01 | 91.74 | <0.3653 |

### B. *Results of the Impact Test*

The impact test energies values were calculated from the absorbed energy formula 1.

$$E = P * D * (Cos\beta - Cos\alpha) \tag{1}$$

Where; $\alpha$- lift angle
$\beta$- Swing angle
P- Weight of the pendulum system
D-Distance from the centre of gravity.
Table II and Fig. 1 gives a summary of the absorbed Charpy impact energy (Kg-m).

TABLE II
ABSORBED CHARPY IMPACT ENERGY (KG-M)

| **Alloy specimen** | $E_1$ | $E_2$ | $E_3$ | $E_{average}$ | **% change** |
|---|---|---|---|---|---|
| Base alloy | 26.156 | 25.971 | 26.256 | 26.128 | - |
| Base alloy + 0.013% Sr | 26.338 | 26.156 | 26.338 | 26.277 | 0.570% |
| Base alloy + 0.4% Fe | 25.588 | 25.391 | 25.588 | 25.522 | -2.319% |
| Base alloy + 0.4% Fe + 0.2% Mn | 25.781 | 26.156 | 26.156 | 26.031 | -0.371% |

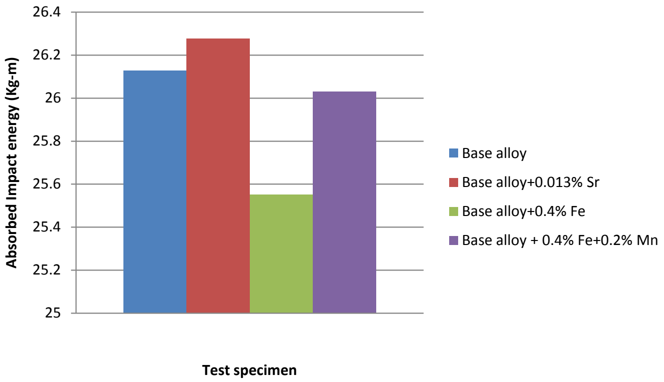

Fig. 1. Graph of absorbed impact energy

### C. *Fatigue Test Results*

Fatigue test was carried out and the results were as shown in Table III, Fig. 2 and Fig. 3

TABLE III
FATIGUE LIMIT (NUMBER OF CYCLES BEFORE FAILURE) FOR THE TEST SPECIMENS

| **Alloy Specimen** | **Limit Stress (Mpa)** | **No. of cycles** | **Remarks** |
|---|---|---|---|
| Base alloy | 20.24 | 800,000 | |
| | | - | Specimen not concentric |
| | 40.48 | 371,300 | |
| | | - | Specimen not concentric |
| | 57.83 | 100,000 | |
| | | 90,000 | |
| Base alloy + 0.013% Sr | 20.24 | 1,100,000 | |
| | | - | Specimen dented |
| | 40.48 | 492,500 | |
| | | - | Specimen broke while machining |
| | 57.83 | 120,000 | |
| | | - | |
| Base alloy + 0.4% Fe | 20.24 | 550,000 | |
| | | - | |
| | 40.48 | 213,300 | |
| | | - | Not concentric |
| | 57.83 | 64,000 | |
| | | 65,000 | |
| Base alloy + 0.4% Fe + 0.2% Mn | 20.24 | 690,000 | |
| | | - | Specimen Dented |
| | 40.48 | 470,000 | |
| | | 500,000 | |
| | 57.83 | - | Not concentric |
| | | 99,500 | |

Micrographs of the specimen were carried out and the results shown in Fig. 4, Fig. 6, Fig. 5 and Fig. 7

## IV. DISCUSSION

TO determine the effect of additives on impact properties and fatigue life of aluminium alloys, it was necessary that comparisons between the base aluminium alloy and the test specimens are made. From the micrographs of the base alloy it was observed that the eutectic silicon in Fig. 4 appeared as a coarse needle-like structures. However, the addition of

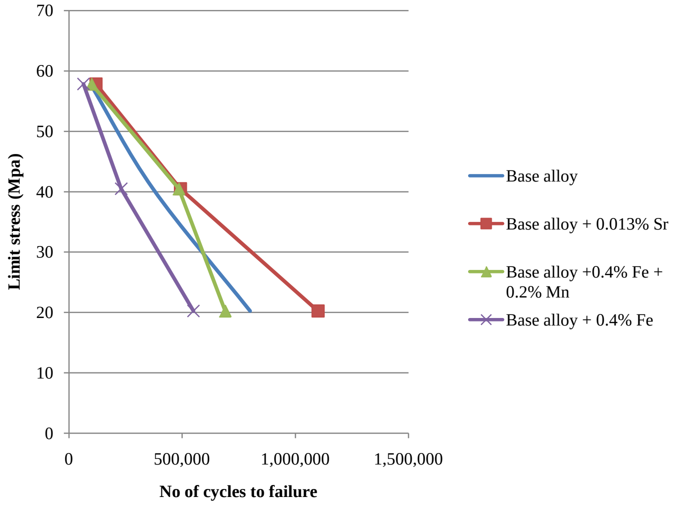

Fig. 2. S-N curves of fatigue stress versus number of cycles

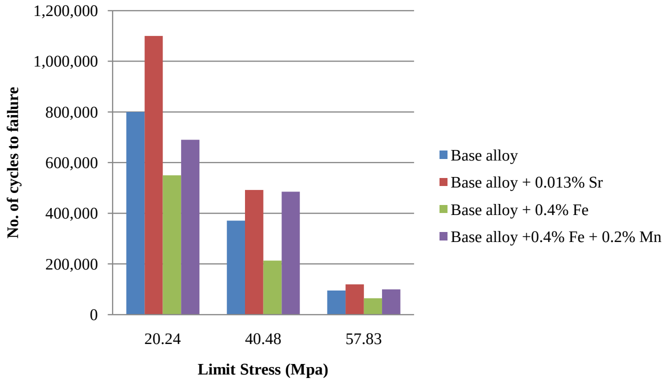

Fig. 3. Comparison bar graph of base alloy and various test specimens

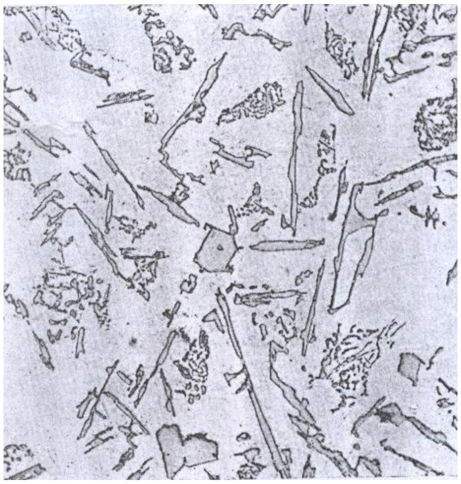

Fig. 4. Micrograph of the as-cast base alloy

Fig. 5. The micrograph of a Strontium modified aluminium alloy

Fig. 6. Micrograph of base aluminium alloy with 0.4wt percent Fe content

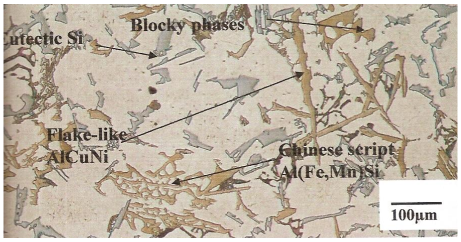

Fig. 7. Aluminium alloy containing 0.4 percent Fe treated with 0.2 percent Manganese

strontium modified the structures to fine fibrous form as observed in Fig. 5. The Fig. 6 illustrated the effect of high-iron content on the structure of the alloy. The micrograph showed needle-like structure of $\beta$-phase (AlFeSi) compound associated with the primary aluminium dendrites. The $\beta$-phase was responsible for the brittleness in the alloy. Addition of 0.2 percent manganese transformed the $\beta$-phase into "Chinese script" that negated the detrimental effect of iron on the impact and fatigue strength as illustrated by Fig. 7.

In testing the impact properties the absorbed energies of the aluminium base alloy, base alloy + 0.013 percent strontium, base alloy + 0.4 percent iron and base alloy + 0.2 percent manganese samples were compared. The absorbed energies were 26.128, 26.277, 25.522 and 26.031 Kg-m respectively as indicated in Table II and Fig. 1. These reflected a 0.57 percent increase to the absorbed impact energy when strontium was added, a 2.139 percent decrease in absorbed energy when iron was added and another decrease of 0.371 percent when manganese was added. The results of fatigue tests were indicated by the data in Table III , S-N curves of Fig. 2 and graphs of Fig. 3. It was found that properties of strontium modified alloy were superior to those of base alloy and iron modified alloy. Addition of iron lowered the number of cycles to failure. Addition of manganese to the alloy increased the fatigue strength of the iron base alloy; consequently manganese neutralized the effect of iron.

## V. CONCLUSION

IT was observed that strontium modification of the silicon phase increases the fatigue strength and the impact properties of the aluminum alloy. Conversely the presence of iron in aluminum alloy decreases fracture toughness values due to the formation of intermetallic compound $\beta$-$Al_5FeSi$. Trace addition of manganese neutralizes the harmful effects of iron in sand cast aluminium alloys resulting in longer fatigue life and improved impact energy.

## ACKNOWLEDGMENTS

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