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Effect of Strontium on Mechanical Properties of Recycled Aluminum-Alloys.

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ABSTRACT
The rapid increase in the utilization of aluminum-silicon alloys (Al–Si alloys) particularly in the automobiles industries due to their high strength to weight ratio, low ductility and low co-efficient of thermal temperature.Therefore, the study is aimed at studying the effects of Sr on the hardness, tensile and impact strength of recycled Al-alloys.Discarded Al-alloys were collected from Old Garage in Osogbo (7.7827^{o}N, 4.5418^{o}E). These samples were cleaned, melted in an electric furnace. The ingot was subjected to compositional analysis using Minipal-4 spectrometer. Ingot and Sr were combined in the proportions of 100/0, 98/2, 96/4, 94/6, 92/8 and 90/10% to produce composites. The composites were homogenized, normalized and subjected to micro-hardness, tensile and impact test were carried out on the composites using Brinell-Hardness Tester (HBP-300P Model), MonsantosTensometer (Xrd-121) and Charpy V-Notch (CVN), respectively.The values of ingot compositional analysis were of Al-12.16%-Si, 4.12%-Cu, 4.30%-Mg. The hardness values, tensile strength and impact strength obtained at 10 (wt. %) Sr were 23.8 BHN, 70.4 MPa and 102J.This modifier improves the mechanical properties of recycled cast Al–alloys and reduces the formation of intermetallic compounds.
KEYWORD – ductility, ingot, compositional analysis, intermetallic.

I. INTRODUCTION

Aluminum can be described as a metal with softness and lightweight with silvery dull type appearance, owing to the thin layer of oxidation quickly formed on exposure to the air. It is non-toxic, non-magnetic and non-sparking (Milleret al., 2017).According to Kaufman and Rooy, (2014) consistent emphasis laid on the reduced weight of aluminum and its alloys has even granted it a high level of application in industries such as automobile and aerospace because the density of aluminum and its alloys is minimal compared with iron and steel. However, the demand of aluminum alloys is on the increase and this is not only limited to automobile and aerospace industries but also in electronics and other peculiar industrial settings because of their excellent machinability and good castability (Das et al, 2019). Meanwhile, aluminum alloys are not often used in as-cast state because it yields relatively poor mechanical properties.

Despite the availability of Al as a major constituent of most productions and the economic/ecological advantages attached to it, not untilearly 1970s that its recycling began to gain wider recognition as both the public and industries took note of the associated benefits (Tepic, et al., 2013). Aluminum recycling is very useful due to the reduced cost of production and short development cycle. In the year 2000, the United States Geological Survey estimated that almost 3.5 million metric tons of aluminum was recovered from purchased aluminum scrap while approximately 40 percent of the total was recovered from old scrap (Paraskevaset al.,2019).The cast aluminum alloys have been found to be useful in the construction of aircraft, buildings and in automobile industries. Aluminum alloys generally contain dangerous pores which must be removed or eliminated because of its negative effects on the mechanical properties of desired materials (Monroe, 2005:Felberbaum and Rappaz, 2011;Durowoju, 2013;Gladson et al, 2015). Strontium, sodium and antimony are used in the foundry industry as modifying agent, by which their addition affected the eutectic crystallization which improves the mechanical properties.

The rate at which discarded Aluminum alloys liter the environment is becoming alarming, with the associated risk and adverse influence on health status of the host communities especially in the event of inappropriate disposal calling for concerted efforts in order to eradicate the

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menace(Babakhani et al.,2018). Asides the inconsistent mechanical/ductility properties, and structural deformation, a major reason why discarded aluminums alloys have not been found worthy for further applications is that they are considered as wastes and cannot be reused.

One of the promising ways by which discarded Aluminum can be made to regain its usual characteristics suitable for various applications is through modification by using modifiers (Das,et al., 2019; Gaustad, et al., 2018). This will not only yield a solid and dependable alloy but also offer a practical means to reduce environmental pollution. Despite previous studies, aluminum alloys obtained from fortification of discarded aluminum alloys with strontium is yet to be investigated. The aim of this research work is to determine the effects of strontium on mechanical properties of recycled aluminum alloys. Also to determine the mechanical properties of aluminum alloys before and after treatment with strontium.

II. MATERIALS AND METHOD

2.1 MATERIALS PROCESSES

This study has some peculiar processes which were executed in order to achieve the set aims. The processes included collection and characterization of discarded aluminums alloys, a typical sample of aluminum alloy with practical application was selected and consequently used to determine the effect of modifier, Strontium concentration on the aluminum alloy. Other processes were sample preparation, compositional analysis of the specimens, mechanical properties of the specimens were evaluated through the micro hardness, tensile and impact tests respectively.

Experimentation involved fortification of the treated raw discarded aluminum with 2kg solid modifying agent, Strontium procured from the Federal Institute of Industrial Research, Oshodi, Lagos. The experiment was repeated 5 times and a total number of 30 samples, including one control each, were prepared for compositional and mechanical properties.A solid cylindrical specimen of 102 mm long and 11 mm diameter pattern was secured for the purpose of casting the specimens. However, scrapper was first used to remove the impurities and inclusions at the top of the molten metal after melting prior to casting(Kosa et al.,2012). The castings were later conducted of which a typical specimen is shown in Appendix. The specimens were further machined at the Fabrication Workshop of Mechanical Engineering,Department, Federal University of Technology, Akure, Nigeria, in order to produce the required specimens. The ingots obtained were treated with different amount of strontium individually as shown in the table below.

Table 1.0: Percentage Composition of Modifier

S/N	Al alloy (%)	Sr (wt. %)
1.	100	0
2.	98	2
3.	96	4
4.	94	6
5.	92	8
6.	90	10

2.2.1 Melting and Casting Procedures

Casting process begins by creating a mould (cavity), which is the 'reverse' shape of the part needed, before the molten metal is poured and the liquid takes the shape of the cavity. The mould is made from a refractory material, that is, sand. The melting was carried out in an electric furnace (Mellen model TC series). 500g of ingot needed to cast each specimen was cut and weighed using electronic weighing balance, re- melted and the molten alloy was treated with strontium as mentioned in the specific objectives. All the samples were prepared in clay mould. The mixture was gently stirred for 3 – 5 minutes and the dross or impurities were removed prior to casting. The patterns of the cast rods were produced using wood.

The pattern was made slightly larger than the expected products thus, giving allowance for shrinkage. Samples with dimension 15mm diameters by 102mm height were prepared. To achieve a good and reliable result, care was taken to maintain constant practice throughout the experimental work. Casts were allowed to cool before removing samples while the solidified metal part was removed from the mould successively.

Plate B2: Pattern of the cast rods

2.3
Mechanical Testing

The mechanical testing was carried out on the specimens to know the mechanical properties which determine their viability**.** Hence**,** the mechanical testing carried out were micro-hardness, tensile and impact testing(Dahleet al., 2019).

2.3.1 Micro-Hardness Test

Micro-hardness test wasperformed on the cast samples using the Brinell Hardness Testing tester HBP-300P in Mechanical Engineering Department, Federal University of Technology Akure, Nigeriia Appendix II. The load of 150g was used for indentation on polished samples. The load was applied for 15 seconds. Diagonal length of square indented was measured by scale attached on the microscope. Hardness was obtained directly from the chart given in the manual for corresponding load and diagonal length.

2.3.2 Tensile Test

The tensile strength of each of the samples was determined using a Monsantos Tensometer tensile testing machine(Xrd 121)in the Materials and Metallurgy Engineering Department, of ObafemiAwolowo University Ife, Nigeria. The machining of the samples into gauge length necessary for the test was also carried out. The initialand final gauge lengths and diameters were recorded for each sample. The difference in the gauge length was recorded against each specimen(Barriero et al.,2018).

2.3.3 Impact Test

The impact test was conducted at Metallurgy and Material Laboratory, ObafemiAwolowo University, Ile-Ife, using the Charpy V-Notch (CVN). The measure of the amount of energy that a material can withstand until fracturing is termed Impact Strength of Toughness. It is important in engineering to know the ability of a material to withstand an impact load until fracturing. Impact test conditions were chosen to represent those most severe conditions relative to the potential for fracture, namely deformation at a relatively low temperature, a high strain rate (i.e., rate of deformation) and a triaxial stress state (which may be introduced by the presence of a notch).

In this experimental work, the Charpy V-Notch (CVN) impact testing machine was used to measure the impact energy of each of the specimen. A V-notch is machined into a bar specimen with asquare cross-section using the V-notch test apparatus and other equipment used for the study.The load is applied as an impact blow from a weighted pendulum hammer that is released from a cocked position at a fixed height "h".. Upon release, a knife edge mounted on the pendulum strikes and fractures the specimen at the notch, which acts as a point of stress concentration for the high velocity impact blow. The pendulum continues its swing, rising to a maximum height "H" which is lower than "h". Based on the difference between h and H, the energy absorption of the specimen was measured.

III. RESULTS AND DISCUSSION

3.1 Chemical Composition of Cast AluminumAlloys

The results of compositional analysis of the as-cast sample and the sample treated with

Strontium were analyzed. The results of the chemical composition performed revealed that the recycled aluminum alloys obtained is primarily composed of Al-12.16%Si- 4.12%Cu-4.30%Mgalloy. The main alloying elements present in the cast aluminum alloys are silicon (Si), copper (Cu), and magnesium (Mg).

3.2 Mechanical Properties of the Strontium Fortified Cast Aluminum Alloys

This section presents the result of the mechanical properties of all the fortified cast aluminum alloys (specimens) through the Brinell hardness, tensile strength and impact strength testing.

3.2.1 Brinell Hardness Values

Table 1.1 Micro-Hardness Test Results

SAMPLE	HARDNESS BRINELL	STRONTIUM (%wt)
1	15.9	0
2	17.8	2
3	18.2	4
4	20.1	6
5	21.5	8
6	23.8	10

The hardness level for the unmodified sample (control specimen) stood at BHN of 15.9, which was observed to be the least value in the line of other values. Similarly, the effects of (Strontium), Sr on hardness values of the cast Al-alloy samples modified with (wt. %)Sr, were investigated respectively. The BHN recorded were 17.8, 18.2, 20.1, 21.5 and 23.8 for 2, 4, 6, 8 and 10 wt. % Sr additions, respectively. The results revealed that in comparison with the hardness value for the unmodified sample, significant increase in the values of hardness was observed. These increases can be attributed to the fact that Strontium altered the size and shape of eutectic silicon phases present in the aluminum alloy (that is, silicon platelets and its morphology).

In addition, the presence of micro-alloying elements such as Fe, Zn, Ni, Pb and Cr in the molten metal contributed to the increase in strength and hardness values of each of the samples, and these are expected to significantly improve some other mechanical properties of the material. As observed in Figure 1.2, optimum hardness values of the modified alloy was obtained at 10 (wt. %) addition of Sr, i.e., 23.8 BHN corresponding to the maximum points above which any increase in percentage of Sr will cause a decrease in the value of hardness.Figure 4.2 revealed that there is a proportional relationship between the BHN and the percentage strontium addition to the recycled aluminum up to 10 wt. %. This established the optimum level of strontium addition to recycled aluminum alloys. Also, Sr addition modifies the eutectic Simorphology from coarse plate-like into fine fibrous and has a beneficial effect on both strength and hardness, which is due to changing the fracture mode from trans-granular andbrittle to inter-granular and interdendritic.

3.2.2 Tensile Strength

Table 1.2 Tensile Test Results

SAMPLE	MAX. TENSILE STRESS(MPa)	STRONTIUM(%wt)
1	65.9	0
2	78.2	2
3	80.6	4
4	94.3	6
5	76.2	8
6	70.4	10

The tensile strengths of the recycled cast Al-alloy modified with Strontium (Sr) were presented in Figure 1.3. The as-cast sample had a tensile strength of 65.9MN/m^2.The tensile strengths

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of the samples increased progressively up to 6(wt. %) addition of Sr corresponding to 94.3868 MPa, above which there certainly was decreased in the strength of the alloys. When compared with the as-cast sample, the modifier had significant effect on tensile strength of the recycled alloy. The material's tensile strength was influenced and this could be attributed to the presence of micro-alloying elements such as Fe (0.35), Mn (0.19), Zn (0.249), Cr (0.016) and Cd (0.0012).In addition, it is evident from the microstructure that the formation of Silicon (Si) particles of regular geometries were found in the Al-alloy modified with 6 – 10 (wt. %) addition of Sr was suggested to have contributed to the decrease in tensile strength. Figure 1.3 showed the values of tensile strength of the samples treated with 0, 2, 4 and 6 (wt. %) of strontium to be (65.9, 78.2, 80.6 and 94.3) MPa respectively.

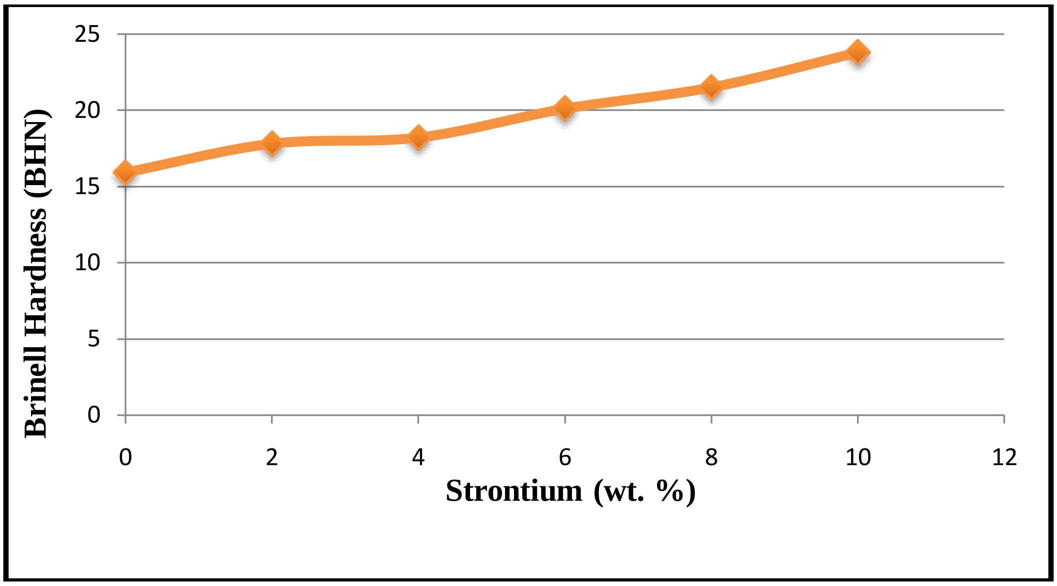

Figure 1.2: Graph of Hardness against % Sr

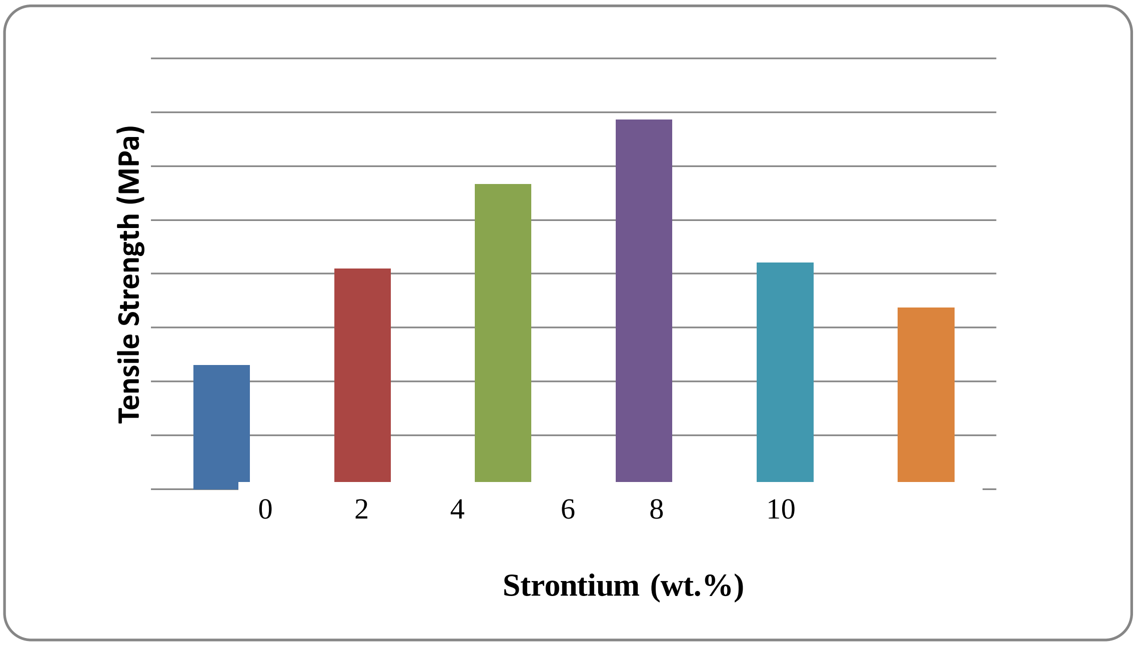

Figure 1.3: Graph of Tensile Strength against % Sr

While from this point a drastic fall in tensile strength values i.e., 76.2 MPa and 70.4 MPa were recorded for the samples treated with 8 and 10 percentage weights of strontium respectively. It was observed that with further addition of strontium above 6 (wt. %), a hypoeutectic structure was formed by the appearance of primary silicon-phase. The silicon platelet changes in shape and size, the grain refinement reduces and formed fibrous silicon structure resulting in low tensile strength.

3.2.3 Young Modulus

Table 1.3 Young Modulus Results

SAMPLE	MODULUS (E-MODULUS)(MPa)	STRONTIUM(%wt)
1	4606	0
2	8195	2
3	11334	4
4	13734	6
5	8406	8
6	6732	10

Figure 1.4 shows the relationship between the Young modulus and percentages of Strontium (Sr) used in fortified the samples. The Young modulus of the samples increase up to 6 (wt. %) addition of Sr above which any addition of Sr led to decrease in Young modulus of the recycled Al-alloy. Further addition of strontium showed a hypoeutectic structure by the appearance of primary Si phase.

3.2.4 Impact Strength

Table 1.4 Impact Test Results

SAMPLE	IMPACT RESULTS(J)	STRONTIUM(%wt)
1	95.2	0
2	100	2
3	97.9	4
4	94.6	6
5	92.5	8
6	102	10

Figure 1.5 shows the relationship between the Impact strength against percentage Strontium (Sr) added to the samples. The optimum impact strength was obtained at 10 (wt. %) addition of Strontium. However, an impact strength of 94.69 J was obtained at 6 (wt. %) addition of Strontium which is in good agreement with the previous result observed in a similar study (Tepic, et al., 2013). The impact strength decreased from 2 (wt. %) of strontium up to 8 (wt. %) of Sr. However, 8 – 10 (wt. %) of strontium, the impact strength increased again. From the result, the unmodified sample of aluminum alloys has impact strength of 95.2 J. At 2 (wt. %) of strontium the impact energy is 100 J.

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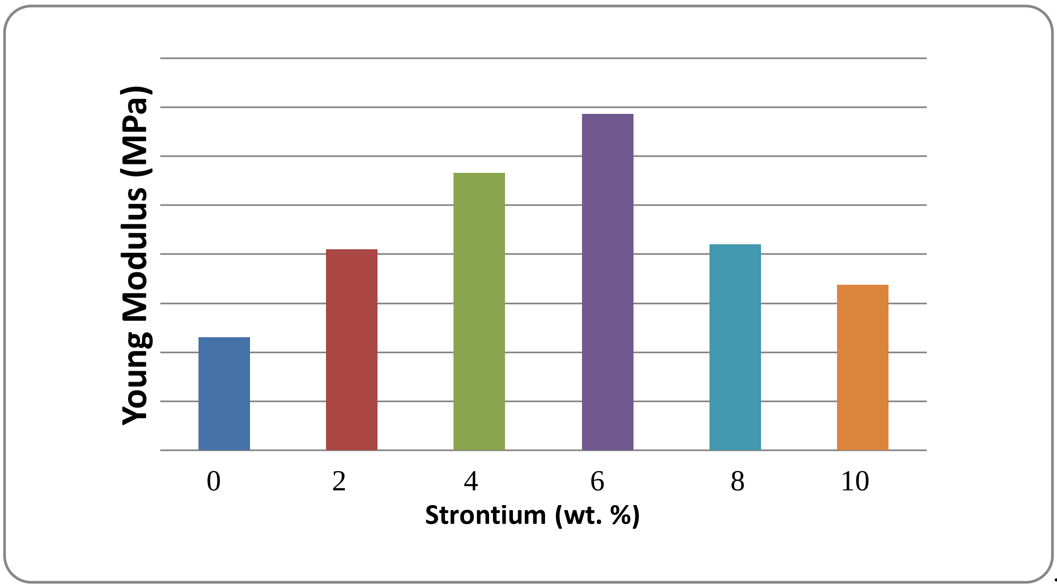

Figure 1.4: Graph of Young Modulus against % Sr

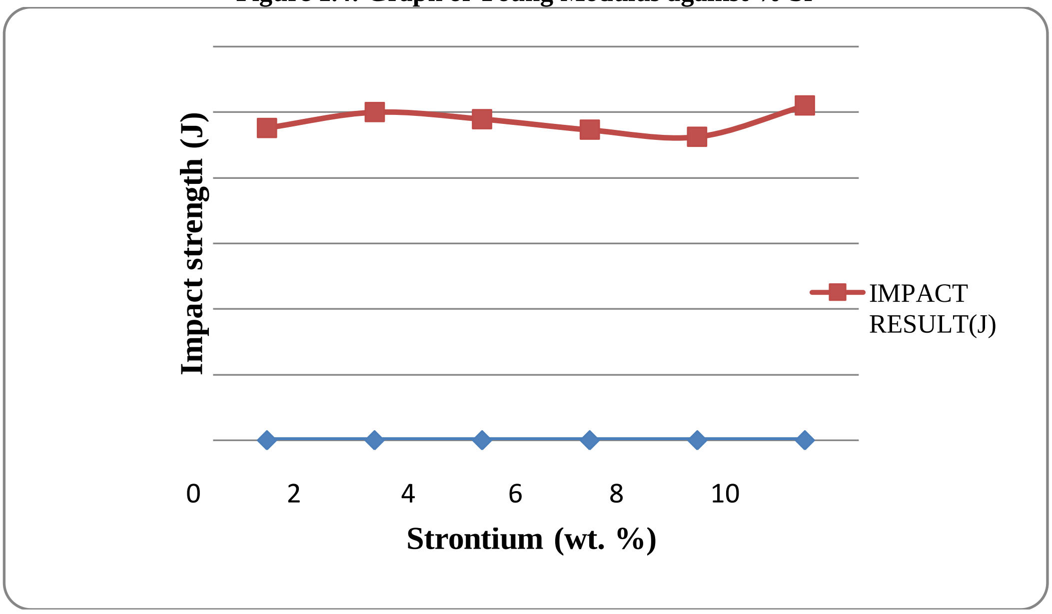

Figure 1.5: Graph of Impact strength against % Sr

There was a decrease in the impact strength to 97.9 J at 4 ((wt. %) . %) of strontium. At 6 (wt. %) of strontium the impact strength was 94.6 J, while, at 8 and 10 (wt. %) of strontium additions, the impact strengths were 92.5 J and 102 J respectively. 8 (wt. %) of strontium has the lowest value of impact energy and the eutectic silicon platelet was affected by the fortifying element. The sizes and shapes of the grains were also affected thereby making the silicon phase to be brittle and coarse.

IV. CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusions

In this research study, the beneficial effects of strontium (Sr) as a modifying agent and its interaction on recycled cast Al – alloys having composition of Al-12.16%Si,-4.12%Cu,--4.30%Mg (wt. %) was investigated. The cast samples were characterized with respect to their compositional, hardness values as well as tensile and impact strengths. The major observations and the conclusions drawn are highlighted below.

1. The results of the chemical composition revealed that the cast recycled aluminum

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alloys obtained was primarily composed of Al-12.16Si,-4.12Cu,-4.30Mg alloy.

2. Furthermore, at 10 (wt. %) strontium addition, the values for BHN, tensile strength and impact strength were 23.8, 104.47N/mm^2 and 102.2 J respectively, beyond which any further increase in concentration of strontium will have adverse effect on the chemical and mechanical properties.

4.2 Recommendations

Future research is required to develop a further understanding of the topic. Therefore the significant recommendations for future research based on the effect of strontium on mechanical properties of recycled aluminum alloysinclude the following:

1. In-depth morphology of inter – metallic compounds such recycled aluminum is needed to be investigated in order to have better understanding of the material having being fortified.
2. However, further research work is required to determine other mechanical properties of the cast Al-alloys (such as compression strength and fatigue strength).

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APPENDIX II (Hardness Test Sample)