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Effect of Ni-additions on the Microstructure and Mechanical Properties of Fe-based Chill-Cast Al-Si Alloys for Production of Pistons for Automobile Engine Applications

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***Abstract* – Effects of Ni addition on the microstructure and mechanical properties of Fe-based chill Al-Si cast alloys have been studied. In this study, both UTS and Hv were the properties used to assess the microstructural changes. The as-cast eutectic alloys were analysed for Fe content using Atomic Absorption Spectrometer and microstructure analysis by Metallurgical Microscope type PMG 3. The results obtained from the study showed that the ratio of Fe to Ni of 1:2 gave a decrease of Fe from 1.7% to 0.12%. The results further indicated that UTS of the as-cast eutectic Al-11%Si0.85%Ni alloy significantly increased with the removal of Fe from 124.05 N/mm2 to 165 N/mm2, whereas Hv decreased from 236.0 to186 respectively for the Ni content of 0.85%. The results are explained in terms of the quantity of Fe removed and confirmed by the high %Fe removal fraction recorded and microstructure analysis results.**

***Keywords* – Ni-Addition, Microstructure, Fe-Based, Chill-Cast, Al-Si Alloys.**

I. Introduction

The Al –Si alloy system constitutes an important engineering material that finds application in many areas. The scope for its utilisation continues to widen because of the focus on high performance lighter weight material for the automobile and allied industries. Al-Si alloys are the major alloys for the production of pistons due to their peculiar properties [1]. Presently, advanced doping techniques and equipment have been used to improve the properties of particular Al-Si alloys with proven results. For example the coarse eutectic structure of Al-Si alloys was refined by the process of modification [2]. The modification process raised the tensile strength from 120N/mm2 -200N/mm2 and the percentage elongation from 5% -15%. Again the solidified Si-platelets (sharp angled) of Al-Si alloy was converted form a flaky structure to globular structure by the addition of a small amount of magnesium (0.3%wt) thereby improving the microstructure and its properties on heat treatment [3]. Most of the investigation on Al-Si alloys have been on eutectic Al-Si alloys [4], because of the castability, good corrosion resistance and good mechanical properties. The ability to refine and improve the melt grains and modify the structure and their useful application properties also are among the factors that make Al-Si alloys attractive and principal cast material of interest among cast aluminium alloys.

The Al-Si alloy system contains iron as an inherent but deleterious impurity [5]. Iron is a common impurity in aluminium and its alloys that is not easily removed which can cause adverse effects to ductility and castability, particularly in Al-Si based casting alloys [6].

Fe and Zn are harmful impurities in Al-Si alloys. Iron forms intermetallic compounds (AlSiFe) with Al and Si in form of coarse crystals, which sharply lower the mechanical properties, especially plasticity and corrosion resistance of alloys [7]. Iron is known to be a deleterious element in Al-Si alloys especially when it is above the critical level. The micro structure of such Al-Si alloy contains flakes of iron inter metallics compounds dispersed throughout it and distinguished by their darker color and morphologies under microscope. [8 and 9].

The effect of iron on mechanical properties of aluminium alloys has been reviewed extensively by [10] and [11] and more authors that as Fe levels increase, the ductility of Al-Si based alloys decreases. This is usually accompanied by a decrease in tensile strength, however in general, the yield strength remains unaffected by iron, unless ductility is affected so much that the alloy cannot even reach yield before brittle fracture occurs. Furthermore, the reduction in both strength and ductility is caused by and increasing amount of coarse AlFeSi crystallites in place of fine eutectiferous silicon [3]. Addition of elements such as Mn, Cr, Be, Co, Mn, Ni, Cu, and others were reported to modify the platelet Ferich phase in aluminium alloys and the dense phase formed as a result of the action of modifiers could be removed by gravitational separation and/or other methods [13]. Eutectic Al-Si alloys with addition of Cu, Ni, Mg and Ti is used for production of pistons for automobile engine applications with water cooling. Cu and Ni impart thermal resistance whereas Cu and Mg raises the mechanical properties through heat treatment [7]. The effect of the third alloying element (metal) is made manifest when the properties of the doped alloys are compared to those of the base alloys [14]. The local bond interaction between atoms of the dopes and dislocations, which is due to surface tension, call also for consideration. Therefore the solubility of the dopes in aluminium alloy and their activities is considered when selecting doping element. In this project, the effect of Ni additions on the microstructure and mechanical properties of Fe-based chill Al-Si cast alloys have been investigated aimed at improving the mechanical properties of Al-Si cast alloys with the objectives to remove Fe from the alloys and to demonstrate scrap reduction of Al-Si alloys through use of solid Al-Si alloy scraps.

II. Methods

Eutectic Al-Si cast alloys of the composition Al-11%Si, Al-11%Si0.85% Ni, Al- 11%Si1.7% Ni, Al-11%Si3.4% Ni and Al- 11%Si5.1% Ni have been produced by melting of the control alloy (and the additions introduced as pure refractory elements) in an electric furnace using metal crucible. Fecorrected Al-11%SiNi alloys were produced and solidified in prepared metal tube. The corrections were done at four dopant to Fe ratios and cast at 720 oC. The tensile strength UTS, of the alloys were determined using Universal Tensile Machine, model TUE-C-100 and of 100KN capacity and the Micro hardness Hv, test was performed using the Micromet 200 series Rockwell testing machine "Buchler", model 60044. Microstructure analysis was achieved using a Metallurgical Microscope (MM) "Olympus C-35AD-4" type PMG 3 which was fitted with a camera. Micrographs have been observed at magnifications of x100, x200, x500 and x800, while photographs were taken at x100 magnification. The chemical analysis of the compositions were carried out using Atomic Absorption Spectrometer and the percentage iron removal fraction evaluated.

III. Results and Discussion

In Table 1, is shown the chemical composition of the solid scrap investigated. The presence of Fe in the eutectic Al-Si alloy also was confirmed by the observed flakes of Fe containing compounds dispersed throughout the microstructure of the as-cast eutectic alloy in Plate1. The phase of Fe-containing compounds were quite obvious within the microstructure of the Al-Si alloy and was distinguished under the metallurgical microscope by their dominant shape (morphology) and colour, thus agreeing with[6].

Table 1: Chemical analysis of the parent alloy

Specimen	Element % wt.				
	Al	Si	Fe	Ca	Other Elements
Scrap Aluminum	82	11	1.7	0.05	5.24

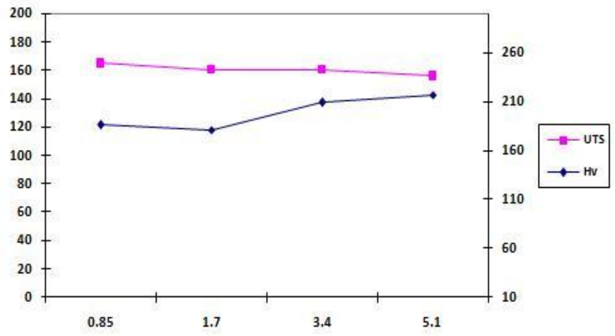

Fig.1. Effect of Ni contents variation on UTS and Hv of chill- Al-11%Si cast alloys.

In fig. 1 is shown the mechanical, UTS and Hv properties of Al-Si alloys plotted as a function of Ni contents. For all the Al-Si alloy systems investigated, UTS exhibited an overall decreasing trend with increasing Ni addition whereas it was an increasing trend for Hv. Initially however, the Hv decreased from186 t0 181 at Ni contents of 0.85% and 1.7% respectively and exhibited increment with higher Ni contents. This could be attributed to equal concentration of Fe and Ni at that point in the alloy. In plates 1-5, MM micrographs are shown for the studied alloy samples, for as cast eutectic alloy (plate 1) and for the homogeneous alloy phase after Fe correction by different Ni contents (plates 2-5).

Table 2: Iron content of parent and chill-doped Al-Si cast alloys showing quantity of Fe removed and the %Fe removal fraction.

S/N.	Alloy Composition	Iron Content, %	Amount of iron removed, %	Iron removal fraction,%
1.	Al-Si	1.70	0.00	00
2.	Al-Si + 0.85% Ni	0.12	1.58	93
3.	Al-Si + 1.7% Ni	0.23	1.47	86
4.	Al-Si + 3.4% Ni	0.23	1.47	86
5.	Al-Si + 5.1% Ni	0.39	1.31	77

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Table 3: Iron content, Ni/Fe ratio, and mechanical properties of chill Al-11%Si%Ni cast alloys

S/N.	Alloy Composition	Iron Content, %	Mechanical and physical properties		
			UTS N/mm^2	Hv	Ni/Fe
1.	Al-SI	1.70	124.05	236.00	0/1
2.	Al-Si +0.85%Ni	0.12	164.86	186.0	**1/2**
3.	Al-Si +1.7%Ni	0.23	160.26	181.0	1/1
4.	Al-Si +3.4%Ni	0.23	160.30	209.0	**2/1**
5.	Al-Si+5.1%Ni	0.39	156.17	217.0	3/1

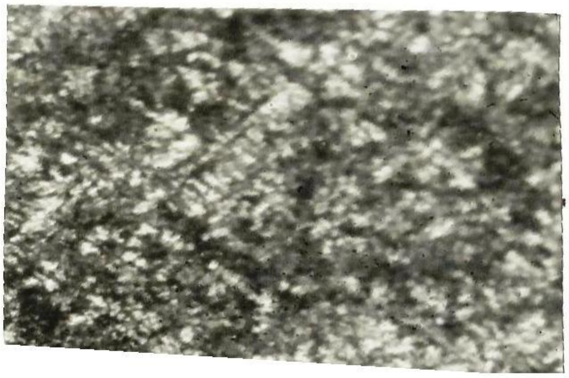

Plate 1: Al-11%Si x100

Plate 2: Al-11%Si0.85% Ni x100

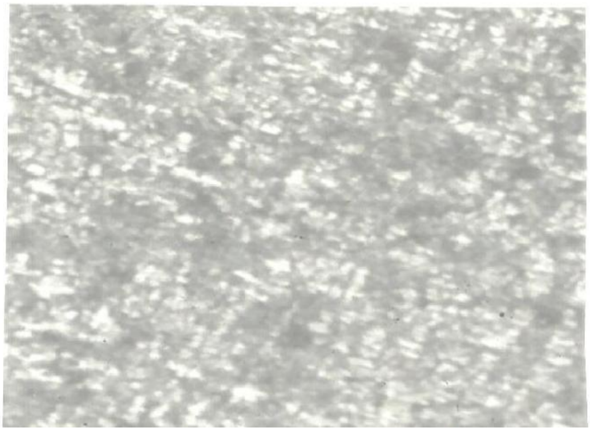

Plate 3: Al-11%Si1.7% Ni x100

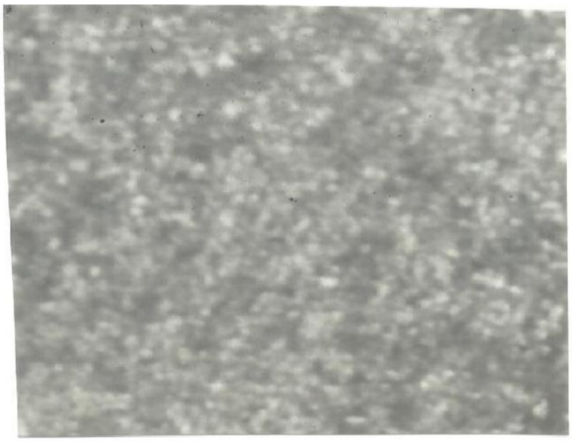

Plate 4: Al-11%Si3.4% Ni x100

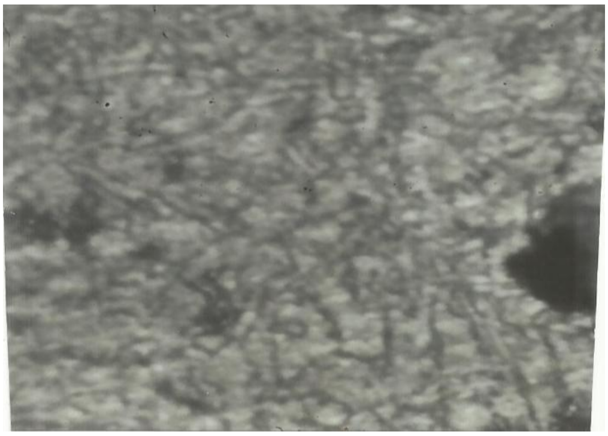

Plate 5: Al-11%Si5.1% Ni x100

The result of the mechanical properties can be explained on the basis of the quantity of Fe removed which was confirm by the high percentage of Fe removal fraction recorded in this investigation. Effect of Ni addition on the mechanical properties of Al-Si alloys confirmed the trend of dependence of mechanical properties on Ni contents. It is shown in Table 2, that UTS of the Ni alloys decreased with increasing contents of Ni and Fe from 165N/ mm2 to 156 N/mm2 whereas Hv increased from 186 to 217 over the same increasing range of Ni and Fe contents. The decrease in UTS could be explained by the reduction in quantity of the basic alloying elements when the dope is introduced due to the formation of chemical compounds [14]. This, notwithstanding the performance of all the Ni alloys as- cast, were significantly higher in the properties tested in comparison with the base alloy thus, agreeing with [3] that the reduction in both strength and ductility is caused by an increasing amount of coarse AlFeSi crystallites in place of fine eutectiferous Si. The microstructure, observed for the alloy with high iron content has an iron-rich primary phase with darker morphology, surrounded by cellular aluminium. The microstructures of Plates 2-5 showed that Fe removal from Al-Si alloys occurred as there were no AlFeSi crystallite (a brittle material which lowered the mechanical properties) observed in comparison to the parent alloy (Plate 1), as a result of the effect of the Ni-addition. Usually, a sharp second phase raises a higher stress concentration and more easily initiates micro crack [15]. The micrographs of the chill-doped cast alloys of Plates 2-5 were observed to be more of improved morphology. Morphology is found to be affected by the alloy concentration.

Observed microstructural features; gain size, Si morphology etc were improved and finely distributed in the homogeneous solid solution The observed lead of the Si-phase over the Alphase at the growth interface of the unmodified eutectic is also seen to have disappeared in the modified structures. The structural changes obtained could be explained through the action of Ni in crystallisation of Fe-rich phase of Al(FeNi)Si, the associated modification by this element and high degree of under cooling of the melt [8 and 9].

IV. Conclusion

The overall results obtained indicated that the low mechanical properties of the investigated cast Al-Si alloys have been improved significantly by Ni additions. The improved chill Al –11%Si0.85%Ni alloy gave the highest UTS and %Fe removal fraction showing that Fe removal favoured the enhancement of the properties. The activities and solubility of Ni in Al-Si alloys proved to be satisfactory at the processing temperature and holding time.

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