International Journal of Emerging Technology and Advanced Engineering
Website: www.ijetae.com (ISSN 2250-2459, ISO 9001:2008 Certified Journal, Volume 6, Issue 12, December 2016)

Variation of Hardness in Combined Refined and Modified Al-15Si-4.5Cu Alloy from Pure Aluminium

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***Abstract* -- This paper tries to investigate the variations in the hardness value of Al-15Si-4.5Cu from pure aluminium under different conditions like after refining aluminium and subjecting the Al-15Si-4.5Cu alloy to modification by, Phosphorous and Strontium, and the combined effect of refiner and modifier, taking into account the changes in microstructure.**

***Keywords* -- Hypereutectic alloy solution, Grain refining, Modifier, Chemical composition, Hardness**

I. INTRODUCTION

Aluminium alloys have found their wide applications in transportation, military and civil aviation industry traditionally [1].Some group of alloys have found their applications in computers, architectural structures and communication systems. Aluminium combined with silicon as major alloying element offers excellent fluidity, corrosion resistance, good machinability and weldability characteristics. Copper addition to Al-Si alloy system improves tensile strength, machinability and thermal conductivity at the cost of reduction in ductility and corrosion resistance[3]. Hardness is one of the important properties of a metal which is to be characterized during material selection.

II. LITERATURE REVIEW

Hardness of a material plays an important role while studying machining and tribiological behavior of it. It was observed that increase in Si content leads to increase in hardness [1,5]. Silicon is present in hypereutectic alloys in two forms (i) primary silicon, in shapes like, stars and acicular flakes in the coarse form and eutectic silicon as a compound with aluminium in inter dendritic spaces distribution and phases in which they are present play a very important role in mechanical properties including hardness[2,3] . The common grain refiners used to refine aluminium are master alloys of Al-T or Al with titan and boron in the proportion of 0.002% -0.03% respectively [1,3,4,5].

Refining of aluminium has no profound effect on hardness [5], but modification of silicon which is normally carried out by either salts of Na,P,Sr etc., or master alloys with aluminum[5]. It is also important not only the silicon content which will influence the hardness but in the hypereutectic region the morphology and topography and distribution of primary silicon also influences it [1,5]. R.Saravanan et.al during their study of effect of silicon content on surface treated Al-Si alloy found as Si content increases hardness also increases. According to Masatsuga Kamiya et al., during their machinability test, they observed the following facts which are due to hardness of material, (i) chip breakability of Al-Si binary castings is optimal between 12 – 15 % of silicon content, (ii) surface roughness is poor initially at 2- 5% of silicon content, optimal at 12% dicreases as silicon content increases and (iii) all forms of tool wear increase with increase in silicon content beyond 15% because of coarse grains of primary silicon present in the mixture. Increasing in copper content in Al-Si based alloys along with increase in strength there will be an increase in hardness[3]. The strength as well as hardness increases with decrease in purity of aluminium with other alloys[6]. H.Kaya et al., during their investigation of effect of temper gradient, growth rate and interflake spaceing on the micro hardness of directionally solidified Al-Si alloy, found that in constant temperature gradient castings growth rate increases micro hardness for a constant growth rate and an increase in interflake spacing decreases hardness. N.A.Ameer et al., during their study on effect of grain refinement and modification on dry sliding wear behavior found that hardness of modified and refined casting is higher than unmodified and unrefined casting which can be attributed to reduced average primary silicon size and modification of eutectic silicon in needle form into fine fibrous form. Combined effect of grain refinement and modification as found in hardness of a refined and modified Al-12Si 4.5cu, compared to as unmodified cast materials is higher because of modification of Si morphology and refinement of α-Al[12].

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International Journal of Emerging Technology and Advanced Engineering
Website: www.ijetae.com (ISSN 2250-2459, ISO 9001:2008 Certified Journal, Volume 6, Issue 12, December 2016)

Mohammed et al., in their study of influence of additives found composition alone will not influence the mechanical properties such as tensile and wear or hardness, the morphology also plays an important role.

III. EXPERIMENTAL PROCEDURE

Various alloys listed in Table 1. were prepared by melting commercially pure aluminum (99.7%) in clay graphite crucible in a pit type resistance furnace under a cover flux (45%NaCl + 45% KCl + 10%NaF) and the melt was held at 720ºC(for 15wt% Silicon alloys and 780ºC for 20wt% Silicon alloys), refiner Al-3B&M51,Modifiers Phosphorous and Strontium , and other required master alloys are added according to the schedule shown in Table 2 . The molds are preheated to 300^{o}C before pouring the molten metal for uniform cooling of melt. After casting specimens for hardness with 25 mm each thick are cut from the cylindrical block of 150 mm length.

Later each specimen is polished with 60 grit on a polishing machine with 120 rpm followed by hand polishing with 200 grit, 600 grit and finally with 800 grit sand papers on a flat surface. After polishing the surface is cleaned with cotton waste to avoid any greasy surface and dust, before it is loaded in hardness testing machine. Before actual testing the machine is checked for errors (calibration) with standard specimen supplied by manufacturer of machine. Proper indenter, load and scale is selected (1/16''steel ball indenter, 100 kg load and Rockwell B scale) in the Rockwell hardness testing machine. For proper indentation (margins from the edge and distance between indentation) a circular gird with 5mm radius offset circles is prepared, with reference to that indentation point is located suitably at 5 points on the surface as shown in the Figure 1. The results are tabulated in Table 3 and represented in the graph in Fig 3 .The microstructure of all the samples is shown in Fig2

TABLE 1
CHEMICAL COMPOSITION OF SAMPLES (A) PLANNED (B) ACTUAL

(a)

Sample No	Composition
Sample 1	Pure Aluminium
Sample 2	Al+Al-3B
Sample 3	Al+M51(5Titanium+1Boron)
Sample 4	Al-15Si
Sample 5	Al-15Si+0.04P
Sample 6	Al-15Si +0.04P+0.06Sr
Sample 7	Al-15Si +Al-4.5Cu
Sample 8	Al-15Si + Al-30Cu+0.04P
Sample 9	Al-15Si +30Cu+0.04P +0.06Sr
Sample 10	Al-15Si + Al-30Cu+0.04P+Al-3B
Sample 11	Al-15Si+ Al-30Cu+0.04P+0.06Sr +Al-3B
Sample 12	Al-15Si + Al-30Cu +0.04P+M51
Sample 13	Al-15Si + Al-30Cu +0.04P +0.06Sr+M51

(b)

Sample No	Si	Cu	Al
Sample 1	0.073	0.053	99.46
Sample 2	0.038	0.050	99.555
Sample 3	0.038	0.035	99.503
Sample 4	14.812	0.006	≈95.5
Sample 5	13.627	0.031	,,
Sample 6	13.953	0.033	,,
Sample 7	13.794	3.740	,,
Sample 8	14.438	4.984	,,
Sample 9	13.021	5.166	,,
Sample 10	13.548	5.438	,,
Sample 11	13.526	5.796	,,
Sample 12	13.117	3.936	,,
Sample 13	13.864	4.043	,,

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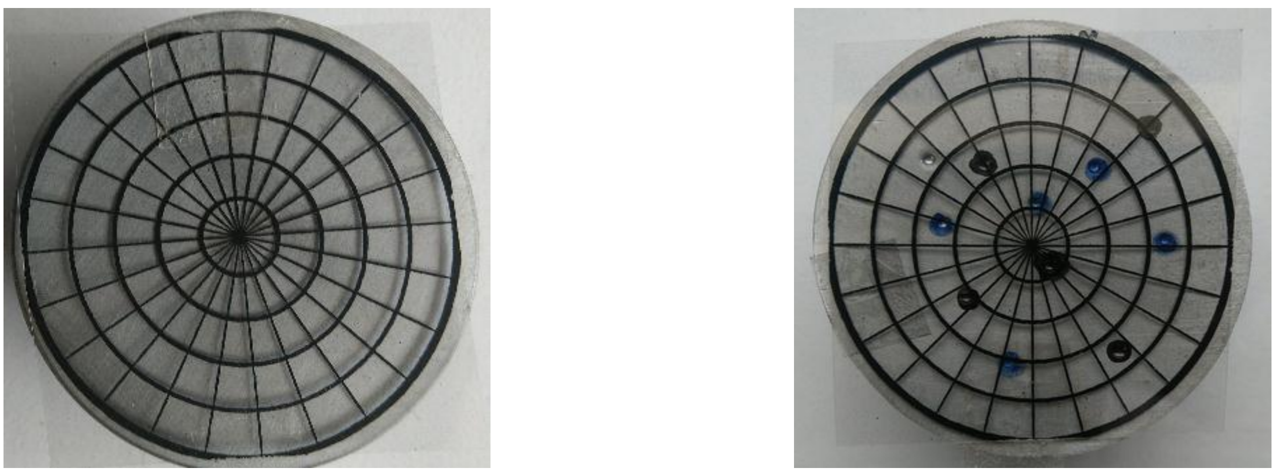
TABLE 2
MELTING SCHEDULE FOR CASTING THE REQUIRED ALLOYS.

Schedule	Melt composition	Addition	Pouring Temperature	Remarks
Melt 1	Pure Aluminium	---	720° C	99.96% purity grade
Melt 2	Al+Al-3B	Al-3B	---	Refiner,1wt%
Melt 3	Al+M51	M51(5Titanium,1Boron)	---	Refiner,1wt%
Melt 4	Al+Al-50Si	**Silicon**	---	15wt%,Remains in all the following melts
Melt 5	Al+Al-50Si+P	Phosphorous	---	Modifier,0.04wt%
Melt 6	Al+Al-50Si +0.04P+Sr	Phosphorous &Strontium	---	Modifiers,0.04wt%,0.06wt%
Melt 7	Al+Al-50Si +Al-30Cu	**Copper**	---	4.5wt%,Remains in all the following melts
Melt 8	Al+Al-50Si + Al-30Cu+P	Phosphorous	---	Modifier,0.04wt%
Melt 9	Al+Al-50Si +30Cu+P +Sr	Phosphorous &Strontium	---	Modifiers,0.04wt%,0.06wt%
Melt 10	Al+Al-50Si+ Al-30Cu+P+Al-3B	Phosphorous& Al-3B	---	Modifier,0.04wt% Refiner,1wt%
Melt 11	Al+Al-50Si+ Al-30Cu+P+Sr +Al-3B	Phosphorous , Strontium & Al-3B	---	Modifiers,0.04wt%,0.06wt% Refiner,1wt%
Melt 12	Al+Al-50Si + Al-30Cu +P+M51	Phosphorous &M51	---	Modifier,0.04wt% Refiner,1wt%
Melt 13	Al+Al-50Si + Al-30Cu +P +Sr+M51	Phosphorous ,Strontium& M51	---	Modifiers,0.04wt%,0.06wt% Refiner,1wt%



a)Before indentation with Grid

b) with indentation (Blue indents are for BHN and Black for Rockwell B scale.)

FIGURE 1.CIRCULAR GRID PLACED OVER THE SPECIMEN TO MAINTAIN APPROPRIATE DISTANCE BETWEEN INDENTATIONS.

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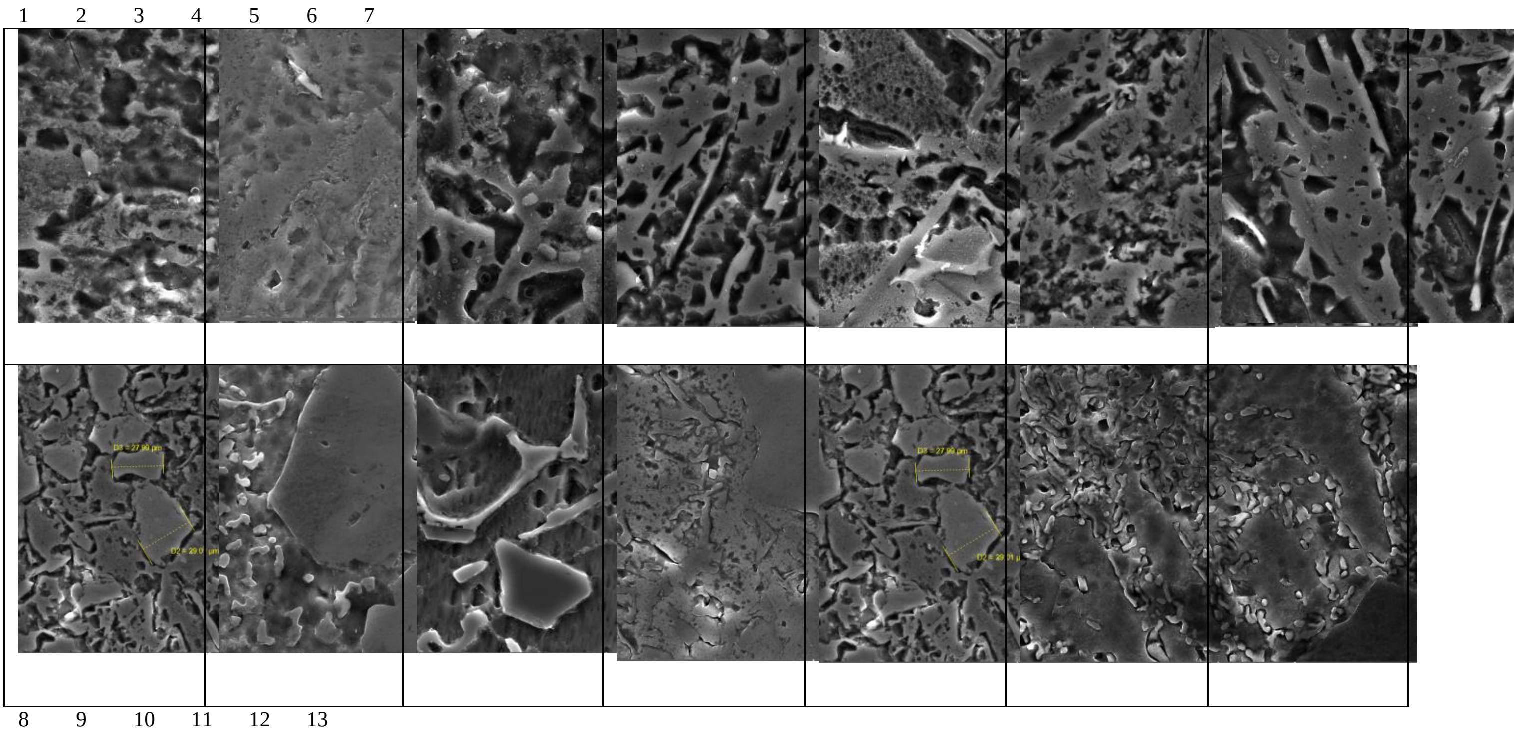

FIGURE 2. SEM IMAGES OF MICROSTRUCTURES OF SAMPLES ETCHED WITH KELLER'S REAGENT 1 -13(X1000)

TABLE 3
HARDNESS VALUES TABULATED.

Sample ID	Composition of alloy	Load(kg)		Readings					Avg of Readings	H R_B Value (Rounded)
		Minor	Major	1	2	3	4	5		
1	(Pure Al)	10	100	50	47	44	49	51	48.2	48
2	(Al-3B)	10	100	55	55	47	54	46	51.4	51
3	(Al+M51)	10	100	59	47	45	51	43	49	49
4	(Al+15Si)	10	100	82	88	84	89	84	85.4	85
5	(Al+15Si+0.04P)	10	100	88	90	88	93	89	89.6	90
6	(Al+15Si+0.04P +0.06Sr)	10	100	88	85	86	82	82	84.6	65
7	(Al+15Si+4.5 Cu)	10	100	40	35	46	47	46	42.8	43
8	(Al+15Si+4.5Cu+0.04P)	10	100	31	33	34	42	41	36.2	36
9	(Al+15Si+4.5Cu +0.04P+0.06Sr)	10	100	32	36	35	38	35	35.2	35
10	(Al+15Si+4.5Cu +0.04P+Al-3B)	10	100	42	43	51	50	54	48	48
11	(Al+15Si+4.5Cu +0.04P+0.06Sr+Al-3B)	10	100	37	40	37	41	38	38.6	39
12	(Al+15Si+4.5Cu+0.04P+M51)	10	100	45	49	49	48	50	48.2	48
13	(Al+15Si+4.5Cu+ 0.06Sr+ M51)	10	100	40	40	42	41	41	40.8	41

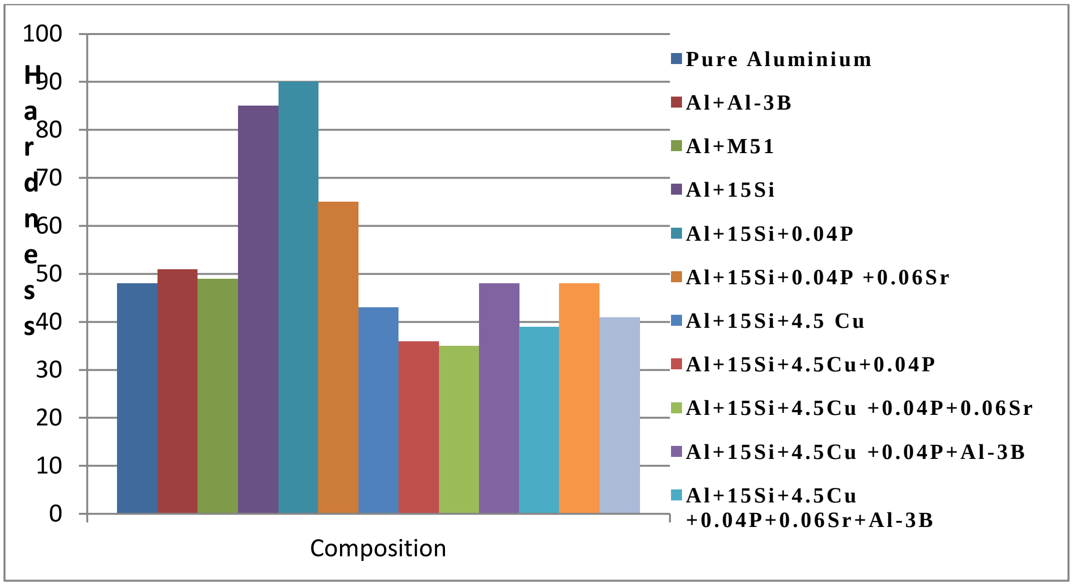

FIGURE 3. GRAPH OF HARDNESS VALUES FOR EACH SAMPLE.

IV. RESULTS AND DISCUSSIONS

In sample 1 which is pure aluminium has primary aluminium with 99.7% purity. When it is refined with Al-3B and 5Ti-1B it is evident from micrographs of sample 2 and 3, that nucleation took place and primary aluminum has attained coarse shape, during this stage there is no significant change in hardness identified. With addition of silicon to the refined mixture an increase of 73% in hardness is observed. This phenomenon can be attributed to coarse star and flake like structure of primary silicon which is evident in microstructure of sample 4.

Further when the alloy solution is modified with Phosphorus and Strontium, hardness is reduced by about 25% because of the modification in the morphology of silicon particles from coarse to fine particles. With Copper addition to the mix hardness is further reduced by 33%. But as compared to unmodified Al-15Si-4.5Cu hardness of modified Al-15Si-4.5Cu casting is slightly increased which indicates complete change in morphology of coarse Si particles to finer form take place completely.

V. CONCLUSION

Refining of pure aluminium with Al-3B and 5T1B has no significant effect on hardness except the grain refinement. The addition of Si increases hardness increases. The copper addition reduces the hardness in the expected lines, which will be reduced further upon modification with Phosphorous and Strontium because of change in morphology.

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