

Evaluation of Vickers Hardness Number of Al-Si Alloy Under Heat Treated Conditions



Jayasheel Kumar K A, C M Ramesha

Abstract: The paper deal with the hardness property assessment of various Al-Si alloys under heat treated conditions. The tested specimens have the compositions of Si with percentages such as 12, 18 and 24. The fabrication of the selected composition is carried out by melting the material to the melting temperature of around 800°C. The material is subjected to solutionised heat treatment for 3 hours at 500°C, 520°C and 535°C and quenched in water. Further aging is carried out at 155°C for 2 hours, 5 hours and 8 hours respectively for 500°C, 520°C and 535°C of solution heat treatment condition. The hardness property is evaluated using Vickers Hardness tester as per the standards of ASTM- E92. Thorough comparison of Vickers hardness number is performed among the as-cast and various heat treated environment. Desirable properties of alloy are observed at 520°C solutionised heat treatment & 5 hours of precipitation hardening at 155°C for 18% of Silicon composition. The hardness value decreases due to the increase in percentage of silicon and the values are observed.

Keywords: Solution Heat Treatment, Age Hardening, Vickers Hardness Tester, Hardness value

I. INTRODUCTION

Composite materials are manufactured from two or more materials with discrete chemical properties, physical properties and mechanical properties, when amalgamated to produce a material with properties unlike the individual material. The composite is found in various forms like ceramic matrix composites, polymer matrix composite, metal matrix composite. MMCs are considered to be the group of materials combined with metals, intermetallic compounds integrated with various reinforcing phases like fibers, whiskers, particulates etc. Aluminum Silicon is aluminum based alloy in which aluminum is considered as matrix material and silicon in majority being the particulate. The alloy considered for the piston material is Al-Si composite. The silicon based aluminium alloy, is associated with the theoretical density of 2.66 g/cm³[1]. Silicon being the primary content of the alloy possesses excellent fluidity property due to which it finds use in various applications such as engine cylinder, piston, manifolds, and motor casings. The material is associated with excellent pressure tightness, high specific strength, and high corrosion resistance.

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The silicon concentration and cooling conditions of the alloys, makes the structure of the casting strong and suitable for the required applications [9]. The development of aluminium grains in the component grow very large, under the specified conditions such as slow cooling, sand castings or heavy sections, that leads to poor casting and reflects on the mechanical properties [8].

There are essentially three types of aluminium piston alloys:

- The most commonly used is eutectic Al-12%Si alloy containing approximately 1% each of Cu, Ni and Mg. This composition is widely used for manufacturing of pistons for commercial vehicles. The key reason underlying the same is the durability and light-weight composition properties [11].
- Hyper-eutectic Al-18%Si containing approximately 1% each of Cu, Ni, and Mg. Studies, conducted over expansive periods of time have proved that this composition demonstrates low thermal expansion and wear properties. On the flip-side, it displays a loss of strength.
- Special-eutectic Al-24%Si containing approximately 1% each of Cu, Ni, and Mg have been developed for better strength properties at higher temperatures. Two of the foremost advantages displayed are its excellent heat transfer properties and reduction in wear properties [10].

A piston is subjected to very high temperature condition along with extreme and sudden compression and tensile forces on combustion as well as on side thrust [6]. Hence, aluminium alloys are used as piston material. Cast Aluminium alloys is poured into the moulds in liquid form and made to solidify into the desired shape. The developed material is subjected to machining process alone rather than subjecting to metal working operations [7]. Figure 1 shows Equilibrium binary Al-Si phase diagram.

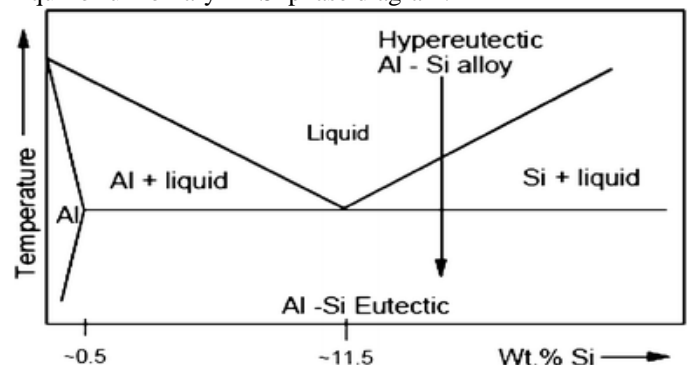


Fig.1 Equilibrium binary Aluminum Silicon phase diagram



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Table 1 shows the physical and mechanical properties of piston alloys at various temperatures [5]

Table 1: Physical and Mechanical Properties of Piston Alloys

Parameters	Eutectic Alloy		Hypereutectic Alloy		Special
	Cast	Forged	Cast	Forged	Cast
Density (Kg/dm ³) at 20 ⁰ C	2.70	2.70	2.68	2.68	2.80
Linear Thermal Expansion Coefficient (1/K) between 20 ⁰ C to 200 ⁰ C	20.5-21.5	20.5-21.5	18.5-19.5	18.5-19.5	20.5-21.5
Thermal Conductivity (W/cm-K) at 20 ⁰ C	1.43-1.55	1.47-1.60	1.34-1.47	1.43-1.55	1.30-1.40
Specific Heat (J/g-K) at 100 ⁰ C	0.96	0.96	0.96	0.96	0.96
Young's Modulus (MPa)					
at 20 ⁰ C	80.000-81.000	81.000	83.000-84.000	84.000	82.000
at 200 ⁰ C	73.000-74.000	-	75.000-76.000	-	78.000
at 250 ⁰ C	68.000-70.000	74.000	-	76.000	72.000
at 300 ⁰ C	-	-	-	-	70.000
Yield Strength (MPa) at temperature					
at 20 ⁰ C	190-230	280-310	170-200	220-280	200-280
at 150 ⁰ C	170-220	230-280	150-190	200-250	-
at 200 ⁰ C	120-170	-	100-150	-	150-200
at 250 ⁰ C	80-110	90-120	80-120	100-140	100-150
at 300 ⁰ C	50-80	-	60-80	-	85-100
Ultimate tensile strength (MPa) at temperature					
at 20 ⁰ C	200-250	300-370	180-230	230-300	210-290
at 150 ⁰ C	180-230	250-300	170-210	210-260	-
at 200 ⁰ C	160-200	-	160-190	-	170-210
at 250 ⁰ C	100-150	110-170	110-140	100-160	130-180
at 300 ⁰ C	80-100	-	90-130	-	100-120
Hot Hardness after 200 hours at temperature: Hardness (HB)					
at 20 ⁰ C	90-125	90-125	90-125	90-125	100-125
at 150 ⁰ C	80-90	80-90	80-90	80-90	80-115
at 200 ⁰ C	60-70	60-70	60-70	60-70	60-75
at 250 ⁰ C	35-45	35-45	35-45	35-45	45-50
at 300 ⁰ C	20-30	20-30	20-30	20-30	30-40
Elongation to Fracture in %					
at 20 ⁰ C	0.3-1.5	1-3	0.2-1.0	0.5-1.5	0.1-0.5
Fatigue Strength (N/mm²)					
at 20 ⁰ C	80-120	110-140	80-110	90-120	90-120
at 150 ⁰ C	70-110	90-120	60-90	70-100	90-120
at 250 ⁰ C	50-70	60-70	40-60	50-70	60-80
at 300 ⁰ C	-	-	-	-	45-60

II. EXPERIMENTATION

Melting and casting: Melting and casting of various aluminium silicon alloys of LM-13, LM-28 and LM-29 is carried out. For melting purpose a graphite crucible coated with fresh lime (dried overnight) is selected and placed in the hearth of the furnace. Figure 2 shows the electrical furnace.



Fig.2 The Electrical furnace

The alloy in the form of plates is kept in the crucible and heated up to a temperature of around 800°C. After the metal attaining the molten condition, the crucible is taken out of the furnace, Skum powder is added for better surface finish and the degassing of the alloy is carried out. Degassing tablets (hexachloroethane) in powder form is added to the metal to avoid blowholes. Sufficient time is given for the reaction to be completed. The dross is skimmed off and the silica additive to the molten metal is ready. The mixture is stirred continuously for uniform distribution. Slag is removed from the molten metal and poured into pre coated and preheated metal moulds. After solidification and casting of the molten metal, the castings are ejected out.

Solution heat treatment: The alloy is procured in rolled condition and is subjected to solutionization for 3 hours at 500°C, 520°C and 535°C followed by water quenching. Figure 3 shows the electric arc heat treatment furnace used for solution heat treatment.



Fig.3 The electric arc heat treatment furnace

Quenching: After heating the samples of were quenched in water, respectively. After the completion of the quench, the samples were removed from the quenching medium and aging was carried out after each quench to relieve the internal stresses. Figure 4 shows the process of quenching.



Fig.4 The process of quenching

Age hardening: Age hardening is carried out at a temperature of 155°C for time duration of 2 hours, 5 hours and 8 hours respectively for all the three solutionized temperatures. Figure 5 depicts the electric furnace for the process of artificial aging.



Fig.5 The electric furnace

Vickers Hardness Test: The test method consists of indenting the test material with a diamond indenter. An angle of 136 degrees between opposite faces are subjected to a load of 1 to 100 kgf and a full load is applied for a time period of 10 to 15 seconds. The two diagonals of the indentation left in the surface of the material after removal of the load are measured using a microscope and their average is calculated. Figure 6 shows the Vickers Hardness Machine and figure 7 shows the hardness specimen

$$HV = \{2PS\sin(136/2)\} / D^2$$

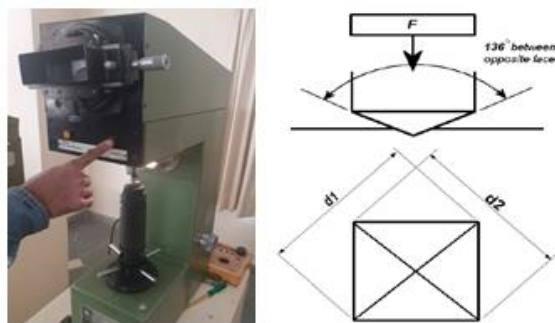


Fig.6 Vickers hardness machine

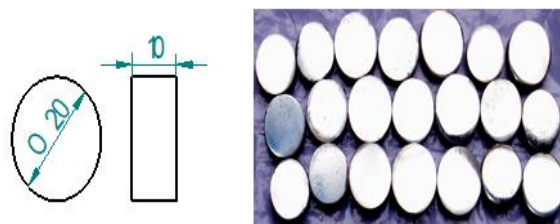


Fig.7 Hardness specimen

III. RESULTS AND DISCUSSION

As Cast Condition: Table 2 shows the HV for various silicon compositions under as cast condition. Figure 8 shows the graph of HV for various silicon compositions under as cast condition.



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Table 2- HV of As Cast Condition

Conditions/ Compositions	Eutectic Al-12%Si				Hyper-eutectic Al-18%Si				Special-eutectic Al-24%Si			
	T ₁	T ₂	T ₃	Avg	T ₁	T ₂	T ₃	Avg	T ₁	T ₂	T ₃	Avg
As Cast	162.5	165.4	171.2	166.4	175	173.4	174.5	174.2	144	140	137	140

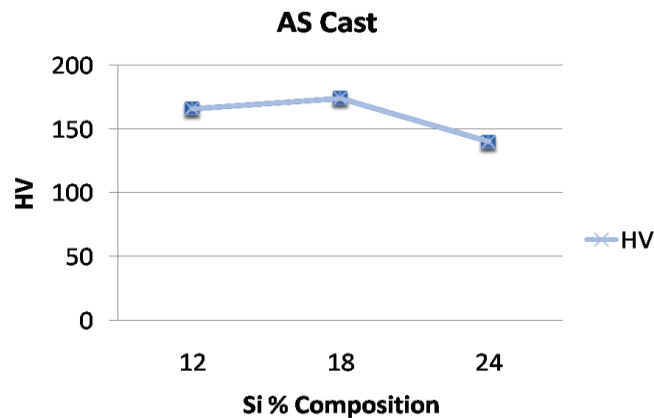


Fig.8 Graph of As Cast Condition

The Vickers Hardness Number of 12% Si is comparatively less than 18% Si. The Vickers Hardness Number further decreases gradually for 24% Si under as cast condition

Solution Heat Treatment of 500°C- 3 Hours: Table 3 shows the HV for various silicon compositions for Solution Heat Treatment at 500°C for 3 Hours. Figure 9 shows the graph the HV for various silicon compositions for Solution Heat Treatment at 500°C for 3 Hours. The Vickers Hardness Number for 12% Si aged for 2 hours is higher than 8 hours and less than 5 hours aged material. The Vickers Hardness Number for 18% Si aged for 5 hours is higher than 2 hours and 8 hours aged material. The Vickers Hardness Number for 24% Si aged for 2 hours is less than 8 hours and 5 hours aged material.

Table 3- HV of Solution Heat Treatment of 500°C- 3 Hours

Conditions/ Compositions	Eutectic Al-12%Si				Hyper-eutectic Al-18%Si				Special-eutectic Al-24%Si			
	T ₁	T ₂	T ₃	Avg	T ₁	T ₂	T ₃	Avg	T ₁	T ₂	T ₃	Avg
(i) Aging-155°C - 2 Hours	172	171	169	170	182	178	181	180	163	164	168	165
(ii) Aging-155°C- 5 Hours	181	184	187	184	203	197	200	200	177	181	182	180
(iii) Aging-155°C- 8 Hours	176	179	183	180	192	190	191	191	172	168	170	170

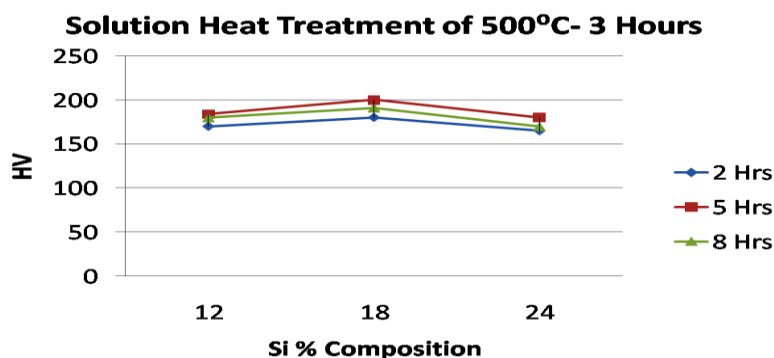


Fig.9 Graph of Solution Heat Treatment of 500°C- 3 Hours

Solution Heat Treatment of 520°C- 3 Hours: Table 4 shows the HV for various silicon compositions for Solution Heat Treatment at 520°C for 3 Hours. Figure 10 shows the graph the HV for various silicon compositions for Solution Heat Treatment at 520°C for 3 Hours. The Vickers Hardness Number for 12% Si aged for 2 hours is higher than 8 hours and less than 5 hours aged material. The Vickers Hardness Number for 18% Si aged for 5 hours is higher than 2 hours and 8 hours aged material. The Vickers Hardness Number for 24% Si aged for 8 hours is less than 2 hours and 5 hours aged material.



Table 4- HV of Solution Heat Treatment of 520°C- 3 Hours

Conditions/ Compositions	Eutectic Al-12%Si				Hyper-eutectic Al-18%Si				Special-eutectic Al-24%Si			
	T ₁	T ₂	T ₃	Avg	T ₁	T ₂	T ₃	Avg	T ₁	T ₂	T ₃	Avg
(i) Aging- 155°C - 2 Hours	202	208	205	205	205	209	214	209	202	198	200	200
(ii) Aging-155°C- 5 Hours	206	211	214	210	218	213	215	215	153	155	158	155
(iii) Aging-155°C- 8 Hours	186	189	193	190	209	207	207	208	142	140	138	140

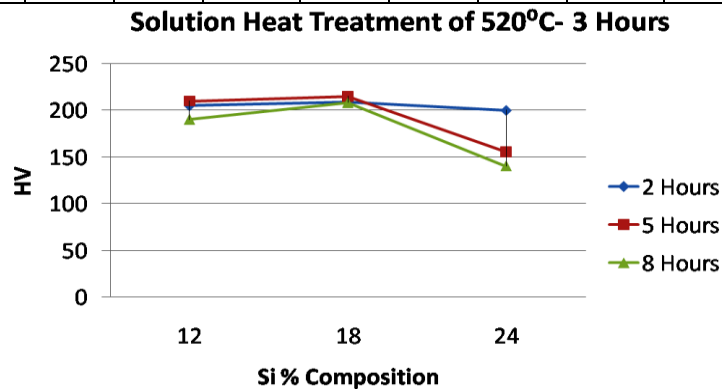


Fig.10 Graph of Solution Heat Treatment of 520°C- 3 Hours

Solution Heat Treatment of 535°C- 3 Hours: Table 5 shows the HV for various silicon compositions for Solution Heat Treatment at 535°C for 3 Hours. Figure 11 shows the graph the HV for various silicon compositions for Solution Heat Treatment at 535°C for 3 Hours. The Vickers Hardness Number for 12% Si aged for 2 hours is higher than 8 hours and less than 5 hours aged material. The Vickers Hardness Number for 18% Si aged for 5 hours is higher than 2 hours and 8 hours aged material. The Vickers Hardness Number for 24% Si aged for 8 hours is less than 2 hours and 5 hours aged material.

Table 5- HV of Solution Heat Treatment of 535°C- 3 Hours

Conditions/ Compositions	Eutectic Al-12%Si				Hyper-eutectic Al-18%Si				Special-eutectic Al-24%Si			
	T ₁	T ₂	T ₃	Avg	T ₁	T ₂	T ₃	Avg	T ₁	T ₂	T ₃	Avg
(i) Aging-155°C - 2 Hours	215	221	218	218	224	226	228	226	214	206	210	210
(ii) Aging-155°C- 5 Hours	216	225	219	220	242	238	240	240	140	144	142	142
(iii) Aging-155°C- 8 Hours	206	214	209	210	220	226	223	223	136	138	140	138

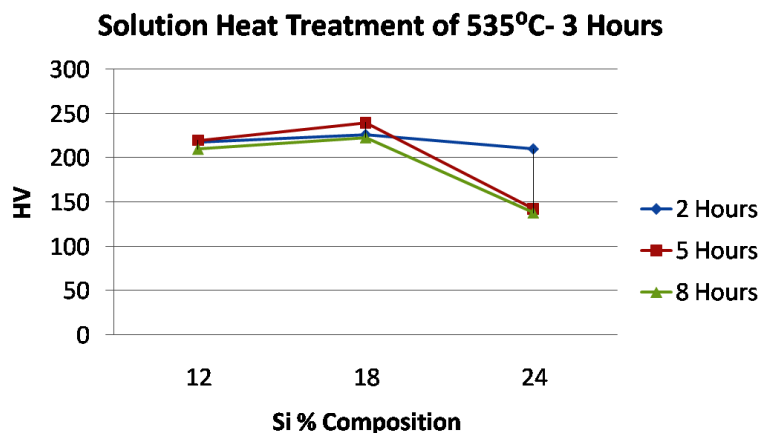


Fig.11 Graph of Solution Heat Treatment of 535°C- 3 Hours

IV. CONCLUSION

As the percentage of silicon increases the hardness value decreases. It is observed from the results of Vickers hardness number that the hardness increases from 12%Si to 18%Si and further increase in the silicon composition to 24% the hardness value tends to decrease. Due to the increase in the solution heat treated temperature the hardness values are increased. The graphs represents the variations in the hardness values for various heat treated and as cast conditions. The hardness values increases for increase in the aging time from 2 to 5 hours and further increase in the aging time reduces the hardness value gradually. Henceforth, the value obtained by aging time of 5 hours gives the optimum values for hardness results.

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