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Effect of Hardness on A413 intermetallic Alloy with the influence of typical heat treatment

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Abstract : *Treatment is an operation or combination of operations involving typical heating and soaking at a temperature for a period of time and methods. The aim is to obtain a desired predetermined property like hardness. Knowing the hardness of any metal or alloy is important, as this value gives you an indication of its ability to form and maintain a shape and is also a guide to its durability. To ensure that any metal or alloy (Al-Si) component is suitable and adequate for the designed purpose, it may need to be exposed to a selected range of typical treatments. The treatments are conducted in such a way so as to ensure that the required combinations of these parameters. A413 is a simple eutectic system with two solid solution phases, fcc (Al) and diamond cubic (Si). The eutectic temperature of Al-Si is around 577 ^{0}C. Considerable interest in replacing cast iron in the automotive industry to improve energy efficiency and meet environmental requirements. A413 alloys have been widely used due to their excellent combination of properties such as low thermal expansion and high wear resistance, corrosive resistance, as well as good castability. Intermetallic elements are added to improve properties and the most commonly alloyed with Titanium, Boron and Strontium. The important outcome of investigation is the fact that aluminium-based alloys, especially Al-Si alloys, which account for their popularity as the chosen materials in wide spread applications, on the hardness of materials under widely varying experimental conditions, a study was therefore planned of the hardness of A413 alloys under typical heat-treated conditions.*

Keywords: *A413, Treatment, Hardness*

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I. Introduction

Hardness of any metal or alloy is important, as this value gives you an indication of its ability to form and maintain a shape, is also a guide to its durability [1]. The hardness test is, by far, the most valuable and most widely used mechanical test for evaluating the properties of metals as well as certain other materials. The hardness of a material usually is considered resistance to permanent indentation. In general, an indenter is pressed into the surface of the metal to be tested under a specific load for a definite time interval, and a measurement is made of the size or depth of the indentation. The principal purpose of the hardness test is to determine the suitability of a material for a given application, or the particular treatment to which the material has been subjected. The ease with which the hardness test can be made has made it the most common method of inspection for metals and alloys.

Treatment is an operation or combination of operations involving heating at a specific rate, soaking at a temperature for a period of time and cooling at some specified rate. The aim is to obtain a desired hardness to achieve certain predetermined. To ensure that any metal or alloy (Al-Si) component is suitable and adequate for the designed purpose, it may need to be exposed to a selected range of conditioning and finishing. The typical treatments are conducted in such a way so as to ensure that the required combinations [2].

The metal in large concentration, the parent metal, is the solvent, and the other elements constitute the solute. Binary aluminum-silicon alloys belong to those alloy systems in which a non-metallic phase, which is present besides a metallic phase in the microstructure, determines the overall properties of the alloy to a large extent. The difference between the density of Al and that of Si quite small, 2.7 g/cm^3 and 2.33 g/cm^3 respectively. Silicon is therefore one of the few elements that can be added to aluminum without essentially changing the density of the latter. However, the hardness and tensile strength of aluminum are considerably increased by the addition of silicon although, naturally, these improvements are accompanied by a loss in ductility. Among the most interesting and most important binary alloys in the Al-Si system are those of eutectic or near-eutectic compositions because of their excellent pour ability (fluidity). Moreover, they are gas and fluid impermeable (pressure-tightness) and can be welded autogenously. Due to the formation of a protecting layer on the surface, they also exhibit good corrosion resistance. The mechanical properties of these alloys are notably sensitive to the size, shape and distribution of the silicon particles present in the microstructure which, in turn, may be manipulated by choosing appropriate solidification conditions or adding suitable additions. Al-Si is a simple eutectic system with two solid solution phases, face-centered cubic (Al) and diamond cubic (Si). The binary Al-Si alloys belong to the simple eutectic system, the eutectic temperature being 577 ^{0} C. But the composition of the eutectic point has been reported ranging from 11.7% - 14.5% Si with the most probable value at 11.7% Si [3]. The eutectic composition in binary Al-Si system is known to shift depending on the alloying elements and cooling conditions or casting processes involved. Eutectic Al-Si alloys [10-13% silicon] find wide applications in marine, chemical, food and domestic, electrical automotive, aeronautical sectors and engine parts. It is well known that metals and alloys solidify with coarse columnar grain structure under normal casting conditions unless the mode of solidification is carefully controlled. It is possible to develop fine equiaxed grain in the cast structure either by increasing the number of nucleation sites or by grain multiplication [3]. There are other methods such as melt agitation and vibration during solidification or use of mold coating. Among all these techniques, grain refinement by inoculation has become the most popular due to its simplicity. The interest in grain refinement technique stems from the fact that the mechanical properties of any metal or alloy component are greatly enhanced by grain size. Grain size is one of the important parameter in determining the mechanical properties of Al-Si alloys and according to Hall-Petch equation [4], high strength can be attained in fine-grained Al-Si alloys.

Attempts have been made in the past to achieve fine equiaxed grain structure by small additions of several elements like Ti, B, Zr, Nb, V, W, Ta, Ce etc. (commonly referred to as hardeners) to molten metal prior to casting. Refining of α-Al grains in Al-Si alloys by means of the addition of elements such as titanium or boron is a common industrial practice [5]. Ti and B containing master alloys find wide popularity, as these were more effective and less expensive than others. Several types of grain refiners in the form of master alloys (Al-B, Al-Ti and Al-Ti-B) are used for grain refinement [3,5]. Eutectic phase comprises of large plates or needles of silicon in the continuous matrix of aluminum. This morphology of silicon is generally termed as acicular silicon. As the coarse plates of silicon are brittle, the eutectic shows low ductility and tensile strength. But, modification is normally adopted by most industries manufacturing to achieve improved mechanical properties. Modification is a melt treatment by which morphology of silicon is changed from angular platelets into fine fibres by the addition of sodium or strontium [3].

II. Literature Review

The hardness of a surface of the material is, of course, a direct result of inter-atomic forces acting on the surface of the Material. We must note that hardness is not a fundamental property of a material, however, but rather a combined effect of compressive, elastic and plastic properties relative to the mode of penetration, shape of penetrator, etc. Hardness seems to bear a fairly constant relationship to the tensile strength of a given material and thus it can be used as a practical non-destructive test for an approximate idea of the value of that property and the state of the metal near the surface. All hardness tests are made on the surface or close to it. We may note that in mechanical tests the bulk of material is involved. Hardness of materials is of importance for dies and punches, limit gauges, cutting tools, bearing surfaces etc.

Hardness measurement can be defined as macro, micro or nano scale according to the forces applied and displacements obtained. Measurement of the macro-hardness of materials is quick and simple method of obtaining mechanical property data for the bulk material from a small sample. It is also widely used for the quality control of surface treatments processes. However, when concerned with coatings and surface properties of importance to friction and wear processes, for instance, the macro-indentation depth would be too large relative to the surface-scale features. Where materials have a fine microstructure, are multi-phase, non-homogeneous or prone to cracking, macro-hardness measurements are appropriate. Micro hardness is the hardness of a material as determined by forcing an indenter such as a Vickers indenter into the surface of the material under 50 to 1000 g load. Usually, the indentations are so small that they must be measured with a microscope. Capable of determining hardness of different micro constituents within a structure, or measuring steep hardness gradients such as those encountered in case hardening [6-9].

The standard test methods according to the American Society Testing and Materials (ASTM) available are, for instance, ASTM E10-07a (Standard test method for Brinell hardness of metallic materials), ASTM E18-08 (Standard test method for Rockwell hardness of metallic materials) and ASTM E92-41 (Standard test method for Vickers hardness of metallic materials) [10]. These hardness testing techniques are selected in relation to specimen dimensions, type of materials and the required hardness [7].

III. Experimental Details

Al-Si alloy (A413) and intermetallic alloys used in the present work were obtained from Mechanical Research and Development Laboratory of our Institute, and the chemical compositions of the same are given in Table 1.

Table 1. Chemical Compositions of the reinforced intermetallic alloys

Alloy Composition	Composition (Wt%)											
	Si	Cu	Mg	Fe	Mn	Zn	Pb	Sn	Sr	Ti	B	Al
A 413	12.5	0.10	0.10	0.60	0.50	0.10	0.10	-	-	0.20	-	Bal
Al-5%Al_3Ti	0.15	-	-	0.20	-	-	-	-	-	5.02	-	Bal
Al-3%AlB_2	0.15	-	-	0.16	-	-	-	-	-	-	2.83	Bal
Al-3%TiB_2	0.15	-	-	0.16	-	-	-	-	-	1.00	2.28	Bal
Al-10%Al_4Sr	0.01	-	-	0.16	-	-	-	-	10.0	-	-	Bal

The base metal A413 added to the induction furnace where the melt held at 720 ^oC. The Degassing agent Hexachloro ethane (C_2Cl_6) used to remove the hydrogen gas bubbles from the molten A413, the overall reaction will be, $C_2H_6 + 6Cl_2 \rightarrow C_2Cl_6 + 6HCl$. The slag formed above the molten metal is removed. Ti, B & Sr were added (optimized wt.% Refer Table 2.) to the molten A413 in the form of master alloys. Titanium (T) and Boron (B) elements assist in finer grain refinement and Strontium (Sr) assist in modification of base metal A413. The base metals along with master alloy are stirred continuously to blend well. The Cover Flux (40% NaCl + 40% KCl + 20% NaF) is added to the molten alloy in order to reduce the melt oxidation, minimize penetration of the atmospheric oxygen, absorb non-metallic inclusions suspended in the melt, keep the furnace wall clean from the buildup of oxides, decrease the content of aluminum entrapped in the dross, remove hydrogen dissolved in the melt and modify silicon inclusions in silicon containing alloys. Now the molten metal from the crucible poured into the mold. When the alloy metal is cooled, it is removed from the mold and turned to standard sizes (20mm diameter and 20 mm length) for hardness test purpose. Now the specimens are polished by both the dry and wet polishing types using the Double Disk Polishing Machine (Ducom- India make). The hardness tests are performed by a Computerized Micro Vickers Hardness Tester (Digital type) according to ASTM E92-41 (Standard test method for Vickers hardness of metallic materials).

Table 2. Test specimen identification of Alloys used.

Specimen composition (Optimized)	Specimen code
A413 (As cast)	1A
A413 + Al-5% Al_3Ti	2A
A413 + Al-3% AlB_2	3A
A413 + Al-3% TiB_2	4A
A413 + Al-10% Al_4Sr	5A
A413 + Al-3% TiB_2 + 10% Al_4Sr	6A

Typical heat treatment methods (optimized) and the reference order is as in the Table 3.

Table 3. Heat treatment (Typical) methods (optimized) and the reference

Typical treatment methods (optimized)	Reference
Untreated	1
Hot steam ejection for 30 minutes	2
Hot steam ejection for 60 minutes	3
Heated at 50 ^0C for 60 minutes	4
Heated at 50 ^0C for 120 minutes	5
Heated in Palm oil at 150 ^0C for 60 minutes	6
Heated in Palm oil at 150 ^0C for 120 minutes	7
Heated in Palm oil at 300 ^0C for 60 minutes	8
Heated in Diesel at 70 ^0C for 60 minutes	9
Heated in Diesel at 100 ^0C for 60 minutes	10

IV. Result and Discussions

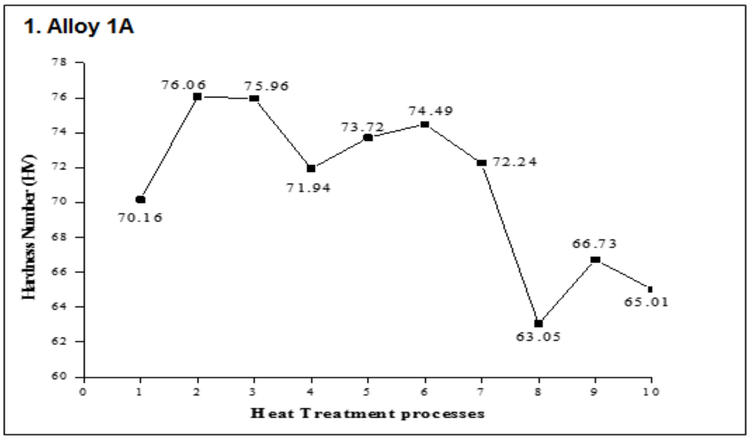

Fig. 1. VHN without heat treatment for Alloy 1A (As cast)

The investigation reviles that for the Alloy 1A (A413 as cast) the hardness increases for the steam ejection for 30 min. heat treated process (76.06 HV) and shows poor hardness (63.05 HV) under the heated in Palm oil at 300 ^{o}C for 60 min., when compare with the untreated hardness (70.16 HV) of A413 as in figure 1.

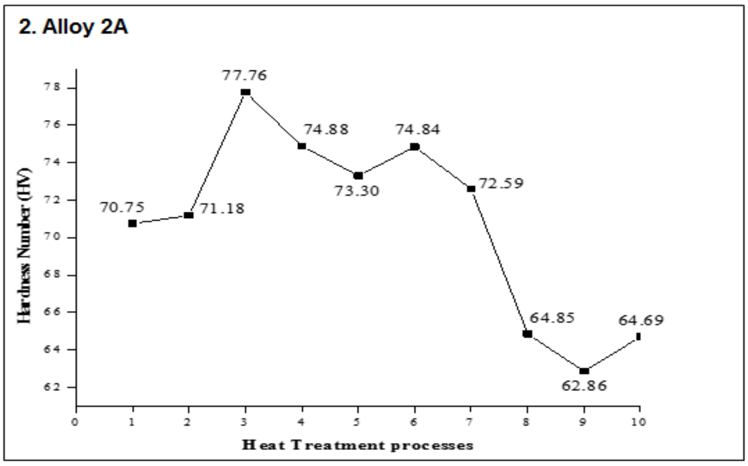

Fig. 2. VHN with heat treatment for Alloy 2A

For the Alloy 2A (with Ti Intermetallics) the hardness increases for the steam ejection for 60 min. heat treated process (77.76 HV) and shows poor hardness (62.86 HV) under the heated in Diesel at 70 ^{o}C for 60 min., when compare the results with the untreated hardness (70.75 HV) of Alloy 2A as in figure 2.

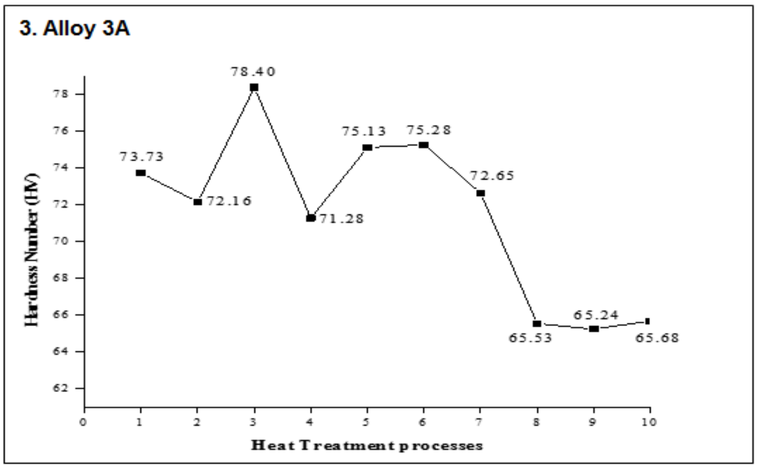

Fig. 3. VHN with heat treatment for Alloy 3A

Results shows that for the Alloy 3A (with B Intermetallic) the hardness increases for the steam ejection for 60 min. heat treated process (78.40 HV) and shows poor hardness (65.24 HV) under the heated in Diesel at 70 ^{o}C for 60 min., when compare the results with the untreated hardness (73.73 HV) of Alloy 3A as in figure 3.

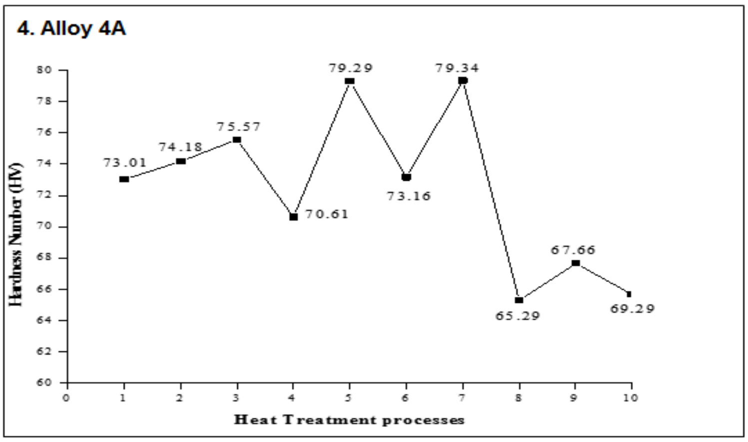

Fig. 4. VHN with heat treatment for Alloy 4A

The investigation reviles that for the Alloy 4A (with Ti and B Intermetallics) the hardness increases for the Palm oil at 150 °C for 120 min. heat treated process (79.34 HV) and shows poor hardness (65.29 HV) under the heated in Palm oil 300 °C for 60 min. and Diesel at 100 °C for 60 min, when compare the results with the untreated hardness (73.01 HV) of Alloy 4A as in figure 4.

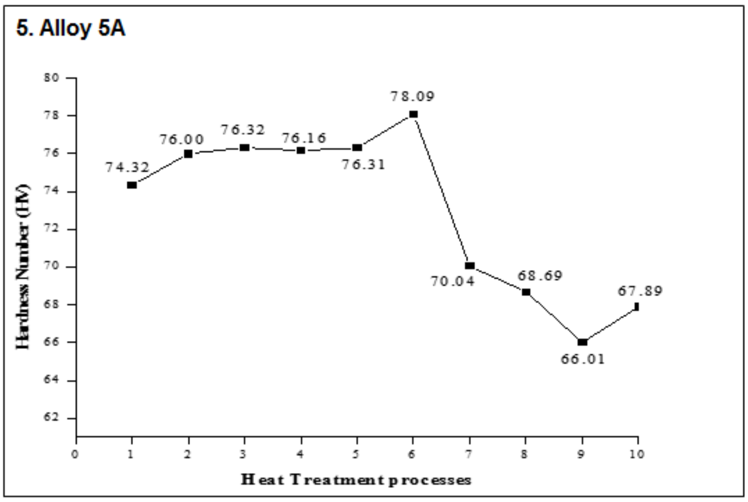

Fig. 5. VHN with heat treatment for Alloy 5A

For the Alloy 5A (with Sr Intermetallics) the hardness increases for the Palm oil at 150 °C for 60 min. heat treated process (78.09 HV) and shows poor hardness (66.01 HV) under the heated in Diesel at 70 °C for 60 min, when compare the results with the untreated hardness (74.32 HV) of Alloy 5A as in figure 5.

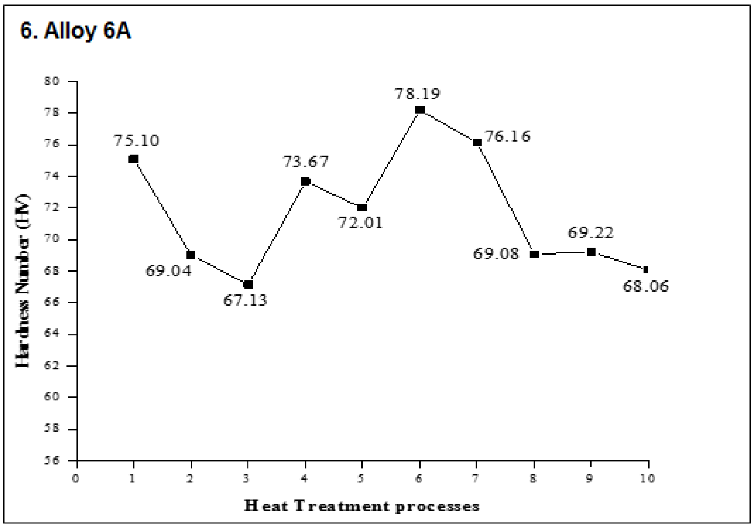

Fig. 6. VHN with heat treatment for Alloy 6A

For the Alloy 6A (with Ti, B and Sr Intermetallic) the hardness increases for the Palm oil at 150 °C for 60 min. heat treated process (78.19 HV) and shows poor hardness (67.13 HV) under the hot steam ejection for 60 min, when compare the results with the untreated hardness (75.10 HV) of Alloy 6A as in figure 6.

V. Conclusions

The following conclusions are drawn with respect to the different typical heat treatments with the developed intermetallic alloys,

1. For Alloy A413 (as cast- 1A)

- Hot steam ejection for 30 min., shows better Hardness, increased from 70.16 HV to 76.06 HV than the 60 min.
- Heated at 50 °C for 120 min., Hardness increased from 71.94 HV to 73.72 HV than the 60 min.
- Heated in Palm oil at 150 °C for 60 min., Hardness increased from 73.72 HV to 74.49 HV than the 120 min.

- Heated in Diesel oil at 70 ^{0}C for 60 min., Hardness increased from 63.05 HV to 66.73 HV than the 100 ^{0}C.

2. For Alloy 2A
- Hot steam ejection for 30 min, Hardness value increased from 70.75 HV to 71.18 HV
- Hot steam ejection for 60 min., Hardness value increased from 71.18 HV to 77.76 HV
- Heated in Palm oil at 150 ^{0}C for 60 min., Hardness value increased from 73.30 HV to 74.84 HV
- Heated in Diesel oil at 100 ^{0}C for 60 min., Hardness value increased from 62.86 HV to 64.69 HV

3. For Alloy 3A
- Hot steam ejection for 60 min., Hardness value increased from 72.16 HV to 78.40 HV
- Heated at 50 ^{0}C for 120 min., Hardness value increased from 71.28 HV to 75.13 HV
- Heated in Palm oil at 150 ^{0}C for 60 min., Hardness value increased from 75.13 HV to 75.28 HV
- Heated in Diesel oil at 100 ^{0}C for 60 min., Hardness value increased from 65.24 HV to 65.68 HV

4. For Alloy 4A
- Hot steam ejection for 30 min, Hardness value increased from 73.01 HV to 74.18 HV
- Hot steam ejection for 60 min., Hardness value increased from 74.18 HV to 75.57 HV
- Heated at 50 ^{0}C for 120 min., Hardness value increased from 70.61 HV to 79.29 HV
- Heated in Palm oil at 150 ^{0}C for 120 min., Hardness value increased from 73.16 HV to 79.34 HV
- Heated in Diesel oil at 70 ^{0}C for 60 min., Hardness value increased from 65.29 HV to 67.66 HV

5. For Alloy 5A
- Hot steam ejection for 30 min, Hardness value increased from 74.32 HV to 76 HV
- Hot steam ejection for 60 min., Hardness value increased from 76 HV to 76.32 HV
- Heated in Palm oil at 150 ^{0}C for 60 min., Hardness value increased from 76.31 HV to 78.09 HV
- Heated in Diesel oil at 100 ^{0}C for 60 min., Hardness value increased from 66.01 HV to 67.89 HV

6. For Alloy 6A
- Heated at 50 ^{0}C for 1hour, Hardness value increased from 67.13 HV to 73.67 HV
- Heated in Palm oil at 150 ^{0}C for 60 min., Hardness value increased from 72.01 HV to 78.19 HV
- Heated in Diesel oil at 70 ^{0}C for 60 min., Hardness value increased from 69.08 HV to 69.22 HV

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