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The effect of particles -addition on the hardness values of 93.95Al-5Zn-1.05Sn alloy

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The effect of particles addition on the hardness values of 93.95Al-5Zn-1.05Sn alloy has been investigated. This alloy was developed at the foundry shop of the National Metallurgical Development Centre, Jos. Apart from the first heat the specimens were produced using stir cast method. The ternary alloy was developed from Al-Zn-Mg system popularly known for their strength by replacing the Mg with tin (Sn). The alloy was hard but addition of alumino-silicate particles to it led to reduced hardness. The product moment coefficient of correlation between the alloy hardness and alumino-silicate particles was -0.58. The work developed a mathematical model which can be used to predict and approximate hardness values of the composite without empirical tests.

Key words: Effect, particles, hardness, alumino-silicate, ternary alloy.

INTRODUCTION

The greatest strength in any known aluminium alloy is obtained by the addition of zinc and magnesium (e.g. 8 wt. percent Zn, 1 wt percent Mg), which form zones and intermediate precipitates leading towards the stable $MgZn_2$ compound. The binary Al-Zn system has favourable solubility and zone and intermediate precipitate characteristics but is not a good age hardening system, at room temperature, because the zinc atom is too mobile and the coarse equilibrium precipitate (Zn) forms at quite low temperature by continuous and discontinuous precipitation (Cottrell, 1980; Higgins, 1985; Khanna, 2008).

Many commercial alloys are greatly improved by the addition of various elements in trace amounts, which are able to enhance or retard the formation of various structures. For example, Cu-Be alloys soften rapidly by discontinuous precipitation at temperatures above about 300°C, but this can be prevented by the addition of about 0.4 wt. percent cobalt. This trace element retards the formation of G.P. Zones and so delays the age hardening process at room temperature, which gives more time for mechanically fabricating the quenched alloy before it becomes too hard (otherwise the quenched alloy has to be refrigerated to keep it soft); and it speeds up the formation of Θ' and also leads to a greater hardness from this precipitate. This work has used 1.05 wt. percent tin as the trace element in the Al-Zn alloy system. Much effort has gone into the study of trace elements in Al-Zn-Mg alloy (Cottrell, 1980; Higgins, 1985; Khanna, 2008). Although very hard, the basic alloy is plagued by grain boundary weakness due to precipitate-free regions. Small additions of silver have a very beneficial effect in refining the precipitate structure and removing the precipitate-free regions. According to Khanna (2008) low tin aluminium alloys possess high fatigue strength and thus can carry fluctuating loads. Literature review has shown that 93.95Al-5Zn-1.05Sn alloy is not a common alloy, therefore the effect of 1.05 wt. percent tin on Al-Zn alloy system will be interesting to investigate. Mg is commonly used but in this work it is replaced by tin. Alloying is used in many different ways to strength metals. The most important general method is to obstruct the movement of dislocations by a fine dispersion of foreign particles

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distributed throughout the matrix crystal. These particles may be single atoms as in solid solution hardening or some larger clusters or separate phases, as in precipitation hardening and dispersion hardening. Particulate composites derive their strength from dispersion hardening and the use of oxide particulates like Al_2O_3, SiO_2, ZrO_2, and TiO_2 in Al, Mg, Cu, Zn and other metal matrices have been pointed out by Curran (1998) and other researchers (Ihom 2012; Ihom *et al.*, 2012a, 2011, 2012b, 2012c).

The objective of this work is to investigate the effect of particles addition of alumino-silicate on the hardness of 93.95Al-5Zn-1.05Sn alloy. Simple linear regression will be used to analyze the relationship between the independent variable the particles and the dependent variable the hardness (Ihom *et al.*, 2009, 2014, 2006).

MATERIALS AND METHODS

The materials used for the work included; alumino-silicate clay, aluminium cables from Cocanaco Cable Company from Kaduna, pure zinc and tin from National Metallurgical Development Centre, Jos stock.

The equipment used included cutting saw, weighing balance, mechanical stirrer, oven, Rockwell hardness tester, grinding and polishing machine, ball mill, nest of sieves and sieve shaker, permanent metal moulds and melting furnace.

The production of the ternary alloy (93.95Al-5Zn-1.05Sn) was carried out in the foundry shop of the National Metallurgical Development Centre (NMDC) Jos. Different heats were produced. The first heat was without the addition of alumino-silicate. The subsequent heats were produced with the addition of varying percentages of alumino-silicates which were produced by using ball mill and sieving the ground alumino-silicate to 20 microns passing. The alumino-silicate addition was varied from 1-5 wt. percent and stirred at 315 rev/ min using a mechanical stirrer. The different heats were removed and poured into permanent moulds for solidification. The specimens were removed and prepared into test pieces for hardness test using Rockwell tester. The details of the test were; Rockwell Hardness 'B' Scale was used, the minor load was 98N (9.8Kgf), the major load was 980N (100Kgf), the indenter was hardened steel ball (1.8mm), the standard test block hardness value was 101.2HRB and the test temperature which was the room temperature was $27^{O}C$. The result of the test is as presented in Table 1. This data was generated in NMDC foundry as earlier stated. All other variables were kept constant alumino-silicate clay particles were the only independent variable.

Development of a simple linear regression model

The basic two variable models (one dependent and one independent variable) is

$$Y = a + bX \quad (1)$$

Which can be solved using the normal equations thus:

$$an + b\sum X = \sum Y \quad (2)$$

$$a\sum X + b\sum X^2 = \sum XY \quad (3)$$

Where,
n, is number of pairs of figures, a and b are constants representing the intercept and the slope. b is called the regression coefficient. X and Y are the variables representing the independent and dependent variables.

The product moment coefficient of correlation r is given by

$$r = \frac{n\sum XY - \sum X \sum Y}{\sqrt{n\sum X^2 - (\sum X)^2} \; X \; \sqrt{n\sum Y^2 - (\sum Y)^2}} \quad (4)$$

From Table 1 calculations of separate regressions of hardness on alumino-silicate particulate variation was done. The separate regressions of the hardness of the composite as Y_H and alumino-silicate particles as X are calculated and shown in Table 2

For regression of the hardness of the ternary alloy Y_H on the wt percent variation of the particulate alumino-silicate clay X

The developed regression equation for the relationship of hardness of the 93.95 Al-5Zn-1.05Sn alloy and particulate alumino-silicate X is

$$Y_H = 30.30 - 0.57X \quad (5)$$

The product moment of coefficient of correlation for this relationship is

$r = -0.58$

$r^2 = 0.34$ (Coefficient of determination)

The developed mathematical model

Equation 5 is the developed mathematical model equation that defines the relationship between the hardness values of the developed alloy and wt percent alumino-silicate particle additions to the ternary alloy. Using this model; calculated values or predicted values have been obtained and placed alongside with empirically generated values of hardness in Table 3.

Table 1. Hardness value variation of the as-cast 93.95Al-5Zn-1.05Sn Alloy with $Al_2O_3.SiO_2$ particulate additions.

Ternary alloy	Weight percent Alumino-silicate particles	Hardness HRB
93.95Al-5Zn-1.05Sn	0	32.33
93.95Al-5Zn-1.05Sn	1	27.90
93.95Al-5Zn-1.05Sn	2	28.80
93.95Al-5Zn-1.05Sn	3	27.70
93.95Al-5Zn-1.05Sn	5	28.50

Table 2. Calculation of the separate regressions with hardness of the composite as Y_H.

S/no.	X	X^2	Y	Y^2	XY
1	0	0	32.33	1045.23	0
2	1	1	27.90	778.41	27.90
3	2	4	28.80	829.44	57.60
4	3	9	27.70	767.29	83.10
5	5	25	28.50	812.25	142.50
∑	11	39	145.23	4232.62	311.10

Table 3. Empirically generated hardness values of the alloy alongside with calculated values using model.

Wt percent alumino-silicate particles (X)	Empirical values of alloy HRB	Calculated values of alloy HRB
0	32.33	30.30
1	27.90	29.73
2	28.80	29.16
3	27.70	28.59
4	-	28.02
5	28.50	27.45
6	-	26.88

RESULTS AND DISCUSSION

The result of this work is extracted from Table 1, equation 5, the product moment coefficient of correlation; which is -0.58, the coefficient of determination which is 0.34 and Table 3.

From Table 1 which is the generated data from NMDC foundry shop shows that at 0 wt percent alumino-silicate particle; the developed alloy has hardness value of 32.33HRB. The alloy (93.95Al-5Zn-1.05Sn) has no particles added to it. According to Cottrell (1980) another approach of developing age hardened alloy is to develop complex alloys, containing several solutions which may precipitate independently or in combination. Thus magnesium and silicon may be added to aluminium to form zones and intermediate precipitates leading towards the very stable Mg_2Si compound. The greatest strength in any known aluminium alloy is obtained by the addition of zinc and magnesium (e.g. 8wt percent Zn, 1 wt. percent Mg) which forms zones and intermediate precipitates leading towards the stable $MgZn_2$ compound'.

In this work the Mg was deliberately replaced with tin (Sn), thinking that precipitates of Zn_2Sn compound will be formed and the strength still maintained. The alloy produced had a hardness of 32.33 which is still good without any age hardening treatment (Cottrell, 1980; Higgins, 1985; Khanna, 2008; Curran, 1998; Ihom, 2012; Ihom *et al*., 2012a, 2011). Alumino-silicate particles of 20 microns size were introduced into this complex alloy as indicated by Table 1 in varying percentages up to 5 wt percent. The aim was to find out the effect of dispersion hardening on the complex or ternary alloy and the relationships are indicated by equation 5 and the product moment coefficient of correlation (r) as well as the coefficient of determination of the relationship of hardness on wt percent alumino-silicate particles. Equation 5 indicates that as the hardness of the ternary alloy which is the matrix increases the particulate alumino-silicate decreases and vice versa. The particulates are supposed to be the reinforcement in this case. The result of the product moment coefficient of correlation (r) is -0.58, which means that there is a moderately strong negative correlation between the hardness of the ternary alloy and the increase in wt percent of the alumino-silicate particles. An increase in the particles will bring about a decrease in the hardness of the ternary alloy. The coefficient of determination of this correlation is 0.34, which means 34 percent in the changes in hardness of this alloy is brought about by changes in wt percent of alumino-silicate particles added; other strengthening mechanism and factors account for the balance. Going by the theory of dispersion hardening in which the strength of the matrix is increased by the action of microscopic particles in impeding the movement of a 'dislocation front', the ternary alloy supposed to increase in hardness with the addition of the alumino-silicate particles rather than decrease (Cottrell etal., 1980; Higgins, 1985; Khanna, 2008; Curran, 1998; Ihom 2012; Ihom et al., 2012a, 2011, 2012b, 2012c, 2009), since such dislocations cannot pass through such particles- assuming that they are harder and stronger than the matrix-'loops' that are formed. These dislocation loops then act as further barriers to the progress of any dislocation fronts which may follow (Cottrell, 1980; Higgins, 1985; Khanna, 2008).

From the aforementioned explanation, it therefore means that the only valid explanation to the product moment coefficient of correlation of the relationship between hardness of the ternary alloy and increase wt percent alumino-silicate particles is that given by Higgins (1985) who said in any metal the presence of a dislocation causes distortion of the lattice structure near it, in a solid solution this distortion- and the strain energy associated with it –can be reduced by the presence of solute atoms. Thus, if the solute atoms are larger than those of the parent metal they will reduce strain in the lattice if they take up sites where the lattice is in tension. If on the other hand the solute atoms are smaller than those of the parent metal they will reduce strain if they occupy sites where the lattice is in compression. Looking at the result in Table 1; this explanation seem to hold, the particles of the alumino-silicate are larger than the atoms of the parent alloy matrix and therefore reduce strain in the lattice leading to reduction in the hardness of the ternary alloy (Khanna, 2008).

Table 3 gives the empirically generated hardness values of the ternary alloy alongside with the calculated values using the developed model. The model has predicted hardness values of the alloy at 4 wt percent alumino-silicate particles and 6 wt percent alumino-silicate particles in addition to giving its own equivalent of the empirical hardness. Even with the developed model the result showed that the addition of alumino-silicate particles to 93.95Al-5Zn-1.05Sn alloy rather reduced the hardness of the ternary alloy instead of increasing it. Table 3 has equally shown that the empirical result is close to the calculated result though they are not exact. The developed model can be used to predict and approximate the hardness value variation with the addition of alumino-silicate particles to 93.95Al-5Zn-1.05Sn alloy (Ihom *et al.*, 2009, 2014, 2006).

Conclusion

The study has investigated the effect of alumino-silicate particulates on 93.95Al-5Zn-1.05Sn alloy and has come up with the following conclusions

1. The study has developed a ternary alloy (93.95Al-5Zn-1.05Sn) by substituting the Magnesium in the popular Al-Zn-Mg system which is known for strength with tin (Sn)
2. The developed ternary alloy has a high hardness of 32.33 HRB which was reduced with the addition of alumino-silicate particles
3. The study showed that the hardness of the alloy had a product moment coefficient of correlation with the alumino-silicate particles of -0.58 indicating a negative correlation
4. The study has developed a mathematical model for the relationship between the hardness of the ternary alloy and the wt percent alumino-silicate content. This model can be used to predict and approximate the hardness of the composite without empirical test.

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