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ANALYZING THE EFFECT OF CASTING DYNAMICS ON THE MECHANICAL PROPERTIES OF ALUMINUM-SILICON ALLOY

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Abstract: *Casting dynamics such as electromagnetic stirring, stirring in gaseous atmosphere, high energy ultra-sound and mechanical vibration when applied during pouring may improve the mechanical properties of Aluminum-silicon alloy. In this work, mechanical vibration was applied to the mold during solidification varying the applied frequencies. Test samples were made, 3 were vibrated vibrated and 1 was not vibrated(As-Cast) Analysis of results obtained shows that the specimen vibrated at 5 Hz has the ability to absorb energy and to resist load and shock within its elastic limit hence it is resilient. This specimen presents all the properties required for a piston alloy .The results obtained practically shows that there would be improved mechanical properties with an increment in the frequency of vibration.*

Keywords: *Effect; Casting dynamics; Mechanical properties; Alloy*

INTRODUCTION

Scientific research has lately demonstrated that the mechanical and properties of metallic materials can be improved not only through alloying or the change of the cooling conditions but also through the application of physical and mechanical treatments during solidification [1].

The physical and mechanical treatments that have been applied so far are:

- *Electromagnetic stirring*
- *Stirring in gaseous atmosphere*
- *High energy ultra-sound*
- *Low frequency mechanical vibrations [2]*

These treatments influence the following factors of the liquid alloy:

a) *The limiting stratum. Due to the application of treatments, the limiting stratum comes off the mould face and thus determines an intensification of the heat transfer from the alloy and mould. This leads to the increase of the diffusion speed and the decrease of the concentration gradient.*
b) *The flow of the alloys. By the application of treatment, whirls are produced that destroy the particles existing between the liquid and the solid phases, thus achieving a constant refining of the melt and an increase of the heat transfer between the liquid and the solid phases.*
c) *Cavitations. The application of treatments brings about the phenomenon of cavitations, i.e. gas bubbles occur that are eliminated through the surface.*
d) *The surface tension and the moistening angle between the heterogeneous grains and the liquid decrease, a fact which brings about leads to an increase in the number of germination centres.*
e) *The degree of under-cooling decreases and leads to less mechanical work done.*
f) *The diphase zone decreases and brings about a reduction of the mechanical work of grain formation. At the end of the solidification process, a greater number of grains is obtained, improving thus mechanical properties of the alloy.*

As a conclusion, due to the application of the physical and mechanical treatment, the alloys obtained have finer grains, their chemical composition is homogenous and the amount of gases in the alloys is reduced [11][14]. All these lead to better mechanical properties.

The vibration of the liquid alloys during solidification by means of low frequency vibrations gives good results, mainly in the case of the non-ferrous alloys but also in steels [7]. Experimentation with mold vibration in order to alter the as-cast microstructure of cast components date back to 1868. In one of the earlier investigations, Chernov found that application of mechanical vibration during solidification of steel caused refinement of austenite. More recent investigations by Abu-Dheir et al shows an effect of mechanical vibrations on the morphology of silicon in Al-Si alloys, which manifests itself in significant enhancement of mechanical properties [17]. Also recent work by Dommaschk showed that a refined grain structure of Al-Si alloys could be obtained by mold vibration.

MATERIAL AND METHOD

Two different kinds of casting were carried out to determine the effect of vibration on the microstructure and mechanical properties of cast aluminum alloys.

In this work, round cast to shape and size test bars were produced using mild steel die mould and subjected to various tests in order to study the effects of vibration on the castings

Sourcing of Materials

The raw material was sourced locally from scraps of automobiles parts like cylinder head, piston etc These were melted in a stationary crucible bale out furnace at 720^{0}C where the alloying with 11% wt silicon took place.

Using a die mould, casting was done at 680^{0}C and allowed to cool under ambient temperature. Further casting was done under vibration for different Frequencies 1, 3 and 5 using a Podmares vibrating Machine. These were also allowed to cool under ambient conditions.

Preparation of the Specimen for UTS

The non vibrated cast specimen and the vibrated specimens were machined to the required shape and sizes (Figure 1) and the universal testing machine was used to subject the specimens to tensile stress shows the readings obtained.

Preparation of Specimens for Hardness Testing

This is the resistance of the specimen to either permanent or plastic deformation. The Brinnel test was carried out on the vibrated and non-vibrated specimens. This consists of indenting the surface of the specimen with a 10 mm diameter steel at a load of between 300kg – 500kg. This load was applied for a time of 30 seconds and the diameter of indentation was measured with a low power microscope after the removal of the load. The brinel's hardness number (BHN) is expressed as the load P divided by the surface area of the indentation.

This is expressed as

$$BHN = \frac{P}{\left(\pi D/_2\right)\left(D - \sqrt{D^2 - d^2}\right)} = \frac{P}{\pi Dt}$$

where P = applied load, kg; D = diameter of ball, mm; d = diameter of indentation, mm; t = dept of the impressions, mm; BHN = kg/mm^2

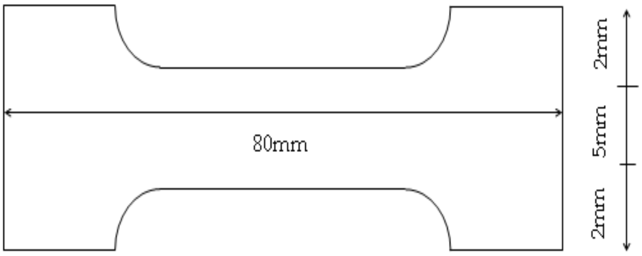

Figure 1: Cylindrical specimen for UTS

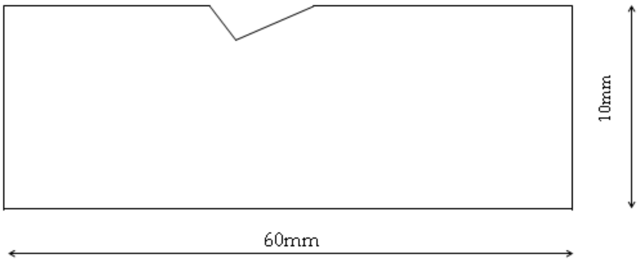

Figure 2: Cylindrical Specimen for Impact Test

Preparation for Impact Test

The specimens were machined to shape and sizes. Using the Mach Avery Testing Machine and a shipping force of 220ft.1b with a velocity of 16.5ft per sec, impact was made on the specimen and the readings were taken.

RESULTS

The Effect of Vibration on the Mechanical Properties.

In the figure 3 the histogram for extension at maximum load and tensile strain at break point are expressed. This shoes that the As-Cast specimen (Normal) has a higher value of extension at break point which means that the material is ductile, this is followed by the vibrated at 5Hz specimen, and the vibrated specimen at 3Hz while the vibrated *specimen at Amplitude 1 has the lowest value. It is also found that the strain at maximum load is the same at the break point which presented a higher value in the Normal specimen followed by the vibrated 5Hz specimen, vibrated specimen Amp1 with the lowest value. This means that the normal specimen (As-Cast) is more deformable than the other 3 when it is loaded with its elastic limit making it move malleable than the others.*

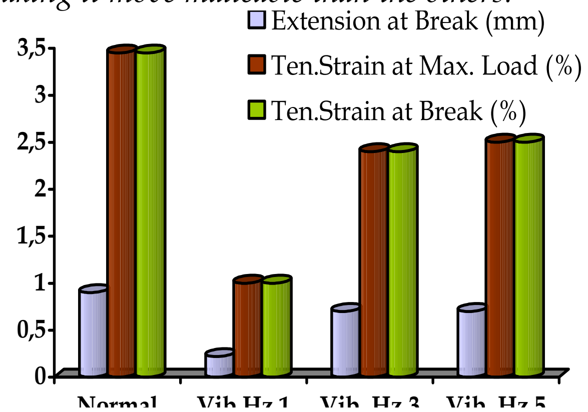

Figure 3: Comparative graph for Extension / strain relationship

In Figure 4 the graph of Load/ Stress relationship reveals that applying the same relationship reveals that applying the same maximum load and standard load at break point the tensile stress of sample vibrated at 3Hz is higher than the Normal specimen (As-Cast) while the specimen vibrated at 5Hz has the higher value.

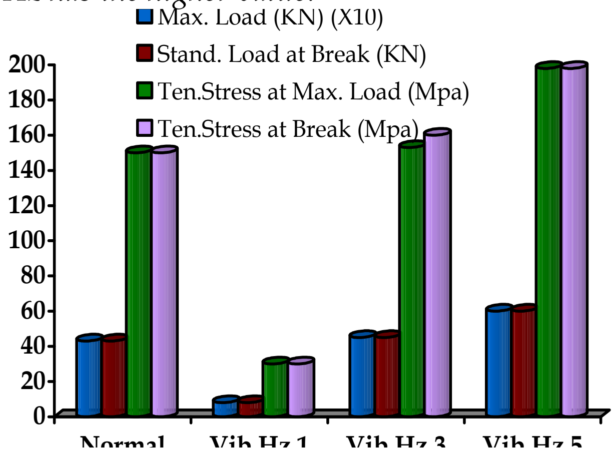

Figure 4: Comparative graph for Load/ Stress Relationship

The specimen vibrated at 1amp has negligible or no effect on the tensile stress. The implication of this is that the specimen vibrated at 5Hz has the highest capacity to withstand stress. We can therefore say that the higher the frequency of vibration during casting the stronger the material. This material is stiff which makes it good for piston alloys.

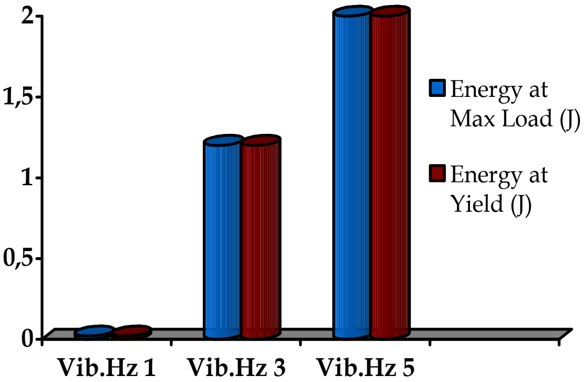

Figure 5: Comparative graph for Energy stored

The graph of Energy as shown in figure 5 reveals that the specimen vibrated at 5amp has the highest Energy at Maximium loading and energy at yield followed by specimen vibrated at 3Hz and specimen vibrated at 1Hz with the lowest value. We can deduce from this that specimen vibrated at 5Hz has the ability to absorb energy and resist load and shock, within the elastic limit hence it is resilent. This specimen presents all properties required for a piston alloy.

Table 1: Results of mechanical tests on vibrated and non-vibrated specimens

Mechanical Properties	*Specimen 1 (Normal)*	*Specimen 2 (VIB. Hz: 1)*
Max. Load (KN)	*4.26*	*0.88*
Tensile Stress at max load (Mpa)	*144.88*	*31.91*
Tensile Strain at max. load (%)	*3.4*	*0.88*
Standard Load at break (KN)	*4.26*	*0.88*
Extension at break (standard) mm	*0.82*	*0.21*
Tensile Stress at break stand (mm)	*144.8*	*31.91*
Tensile Strain at break(stand)mm	*3.4*	*0.88*
Tensile stress at yield(MPa)	*0*	*0*
Modulus(E) (Mpa)	*10181.34*	*0*
Energy at break (J)	*2.2*	*0.04*
Energy at max. load(J)	*2.2*	*0.04*
Energy at yield (J)	*0*	*0*
Extension at yield(mm)	*0*	*0*
load at yield	*0*	*0*
Tensile strain at yield mm/mm	*0*	*0*
Pressure Ratio	*0*	*0*
Energy at X 0 Intercept (J)	*0.00044*	*0*
Impact Force Kgm/s2	*0.81*	*0.54*
Hardness in HB	*105*	*74.1*

Table 1: Results of mechanical tests on vibrated and non-vibrated specimens (continuing)

Mechanical Properties	Specimen 3 (VIB. Hz: 3)	Specimen 4 (VIB. Hz: 5)
Max. Load (KN)	4.28	6.2
Tensile Stress at max load (Mpa)	157.12	193.32
Tensile Strain at max. load (%)	2.31	2.4
Standard Load at break (KN)	4.28	6.26
Extension at break (standard) mm	0.56	0.58
Tensile Stress at break stand (mm)	157.12	193.32
Tensile Strain at break(stand)mm	2.31	2.4
Tensile stress at yield(MPa)	0	
Modulus(E) (Mpa)	10986.71	11709.15
Energy at break (J)	1.19	1.9
Energy at max. load(J)	1.19	1.9
Energy at yield (J)	0	
Extension at yield(mm)	0	0
load at yield	0	0
Tensile strain at yield mm/mm	0	0
Pressure Ratio	0	0
Energy at X 0 Intercept (J)	0.00163	0.01308
Impact Force Kgm/s2	0.81	1.08
Hardness in HB	87	125

Table 2: Result from impacting test

Frequency	Vibrated applied force (Kgm/s^2)	Applied force ($lb. ft/s^2$)
1	0.54	4
3	0.81	6
5	1.08	8
	NON-VIBRATED	
	0.81	6

Table 3: Result from hardness test

Frequency	Vibrated HB	Non-Vibrated HB
1	74.1	
3	87	105
5	125	

DISCUSSION - Comparative Analysis of Mechanical Properties for Vibrated and Non-Vibrated Specimen

One of the aims and objectives of this research work is to induce good mechanical properties in casting of components through vibration. The summary of test results is shown in table 3 and interpreted as follows:

In figure (3) the histogram for extension at breakpoint, tensile strain at maximum load and tensile strain at break point are expressed. This shows that the As-Cast specimen (Normal) has a higher value of extension average point which means that the material is ductile, followed by the specimen vibrated at 5Hz and the specimen vibrated at 3Hz while the specimen vibrated at 1 Hz has the lowest value. It is also found that the strain at maximum load is the same at breakpoint which presented a higher value in the normal specimen followed by the vibrated specimen at 5Hz, vibrated specimen at 3Hz and vibrated specimen at lamp with the lowest value. The implication is that the normal specimen (As-Cast) is more deformable than the other 3 specimen when it is loaded within its elastic limit making it more malleable than the others.

In figure (4) the graph of load/stress relationship reveals that applying the same maximum and standard loads at breakpoint, the tensile stress of sample vibrated at 3 Hz is higher than the normal specimen (As-Cast) while the specimen vibrated at same has a higher value, the specimen vibrated at 1 Hz has negligible or no effect on tensile stress. The implication of this is that the specimen vibrated at 5 Hz has the highest capacity to withstand stress. We can therefore deduce that the higher the frequency of vibration during casting the stronger the material.

However, what we cannot confirm is that at what point would increment in the frequency of vibration have negative effect on mechanical properties. This material is stiff and that makes it suitable for piston alloy.

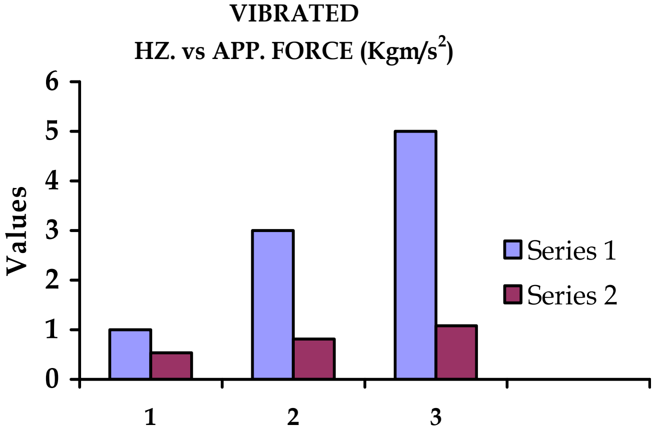

Figure 6: Comparative graph of applied force and frequency

Energy relationship between vibrated samples alone figure (5) reveals that the specimen vibrated at 5 Hz has the highest energy at maximum loading and energy at yield, thus is following by specimen vibrated at 3 Hz while the specimen vibrated at 1 Hz has the lowest.

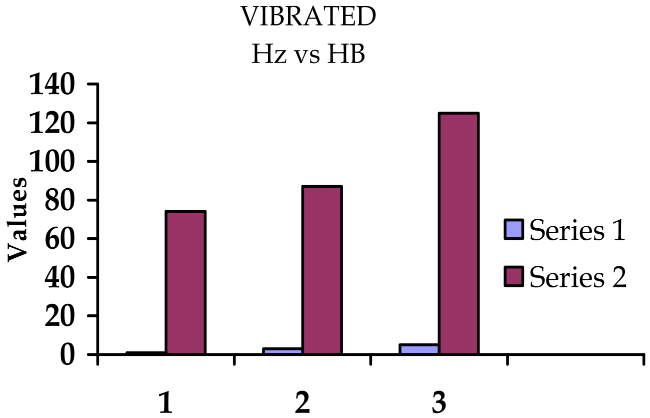

Figure 7: Comparative graph of frequency and Hardness value

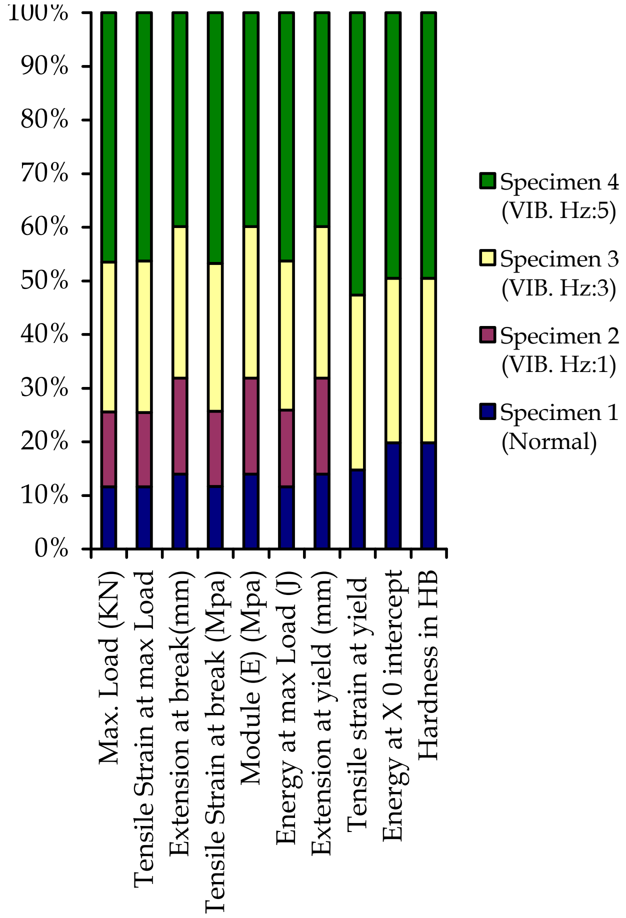

Figure 8: An overview of selected mechanical properties for all specimens

We can deduce from this that the specimen vibrated at 5 Hz has the ability to absorb energy and to resist load and shock within its elastic limit hence it is resilient. This specimen presents all the properties required for a piston alloy, however, what happens after this level is recommended for further work.

An overview of the mechanical properties of all the vibrated components shown in Figure (8) shows practically that there would be an increment in mechanical properties with an increment in the frequency of vibration.

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