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Effect of electromagnetic stirring on the solidification morphology and mechanical properties of Al - alloys.

By

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ABSTRACT

Three different Al-alloys were solidified in metallic molds under the application of magnetic field and direct current with the aim of improving its structure and mechanical properties. The results obtained from these experiments indicate that increasing the stirring power causes a remarkable grain refinement and improvement in the mechanical properties.

The stirring force which was created from the interaction between a magnetic field of 1860 Gauss and a direct current of 230 amperes, improves the ultimate tensile strength of the commercial pure Al(99.5%) by about 20% and its hardness by 42%. Corresponding values were (61% and 30%) and (62% and 25%) for the Al-4.3% Cu and the Al-11.7% Si alloys respectively.

This improvement is most probably due to crystal multiplication and dendritic arms shearing.

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I. Introcuction

The application of electromagnetic field and direct current on the liquid metal during solidification causes a considerable electromagnetic induced motion inside the melt.

The resulting electromagnetic force (Lorentz's force) can be given by (1) :

$$F_x = I_z \; B_y \; H \quad \text{newtons} \quad .... \; (1)$$

Where:

B_y = Magnetic flux along y-axis in Teslas. (1 Tesla = 10^{-4} Gauss)

I_z = Direct current along z-axis in amperes.

H = Height of the liquid metal from the bottom of the mold in meters.

x,y and z are the three axis as shown in fig.(1).

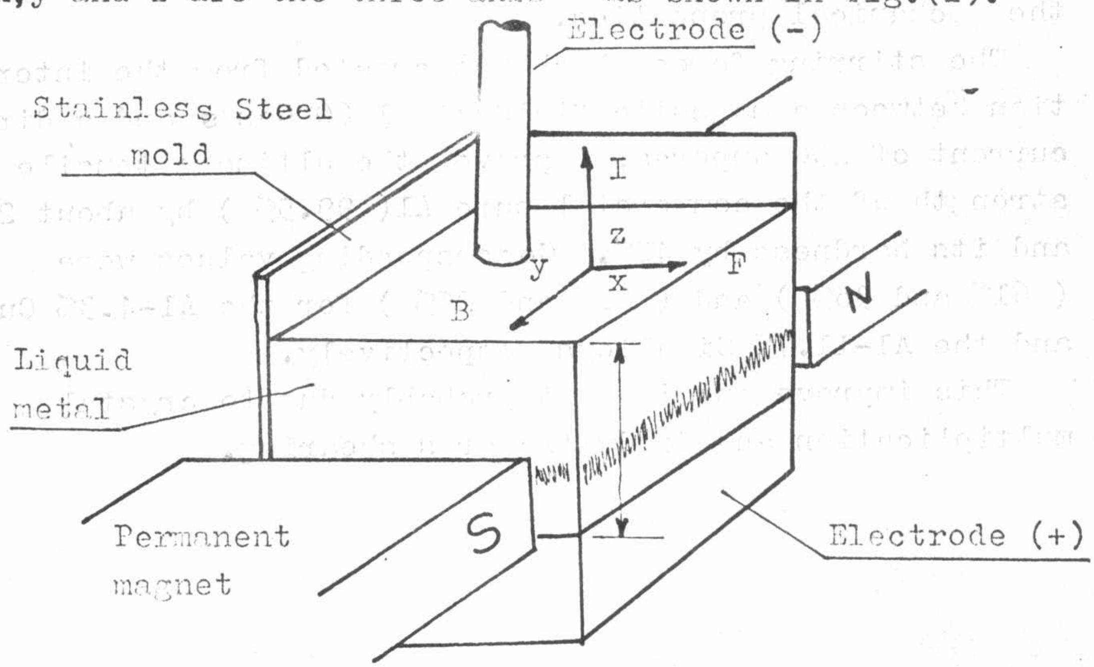

Fig.(1) A sketch showing how artificial convective flow is produced.

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The electromagnetic stirring transports hot metal from the central region of the casting, remelts the solidification front, and creates crystallites which serve as nuclei for new grains in the process of crystal multipication (2,3,4).

The aim of the present work is, therefore , to study the effect of the stirring force on the structure and mechanical properties of commercial pure aluminium (99.5%), Al-4.3% Cu, and Al-11.7% Si alloys, by changing either the magnetic field and /or direct current applied on the molten metal during solidification .

II. Experimental Procedure :

Fig.(2) , shows the experimental arrangement for producing the electromagnetic force by the interaction between the applied magnetic field and direct current .

Casting of the Al-alloys ingots was carried out inside a metallic mold with the shape and dimensions as shown in figure (3) .

Macrostructural investigations were carried out on sections of the Al-99.5% ingots and microstructural examinations were carried out on samples of the Al-11.7% Si alloys using the optical microscope .

Tensile tests and hardness measurements were carried out on the samples machined out of these ingots from locations as shown in figure (3).

The pouring temperatures were 710 ^{o}C for the Al-99.5% , 700 ^{o}C for the Al-4.3% Cu, and 620 ^{o}C for the Al-11.7% Si alloys .

Magnetic field with magnetic flux intensity ranging from 540 to 1860 Gauss and direct current of 100 to 230 ampers were applied to the castings.

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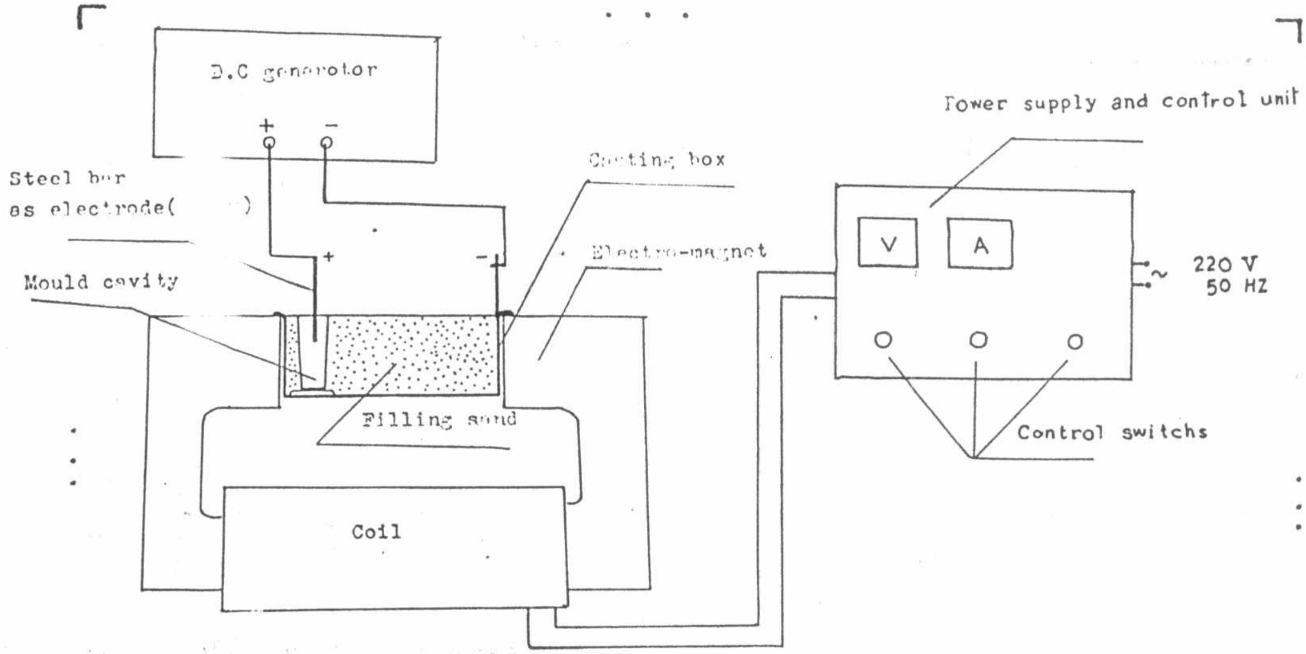


Fig.(2) Experimental arrangement for producing electromagnetic forces inside the casting.

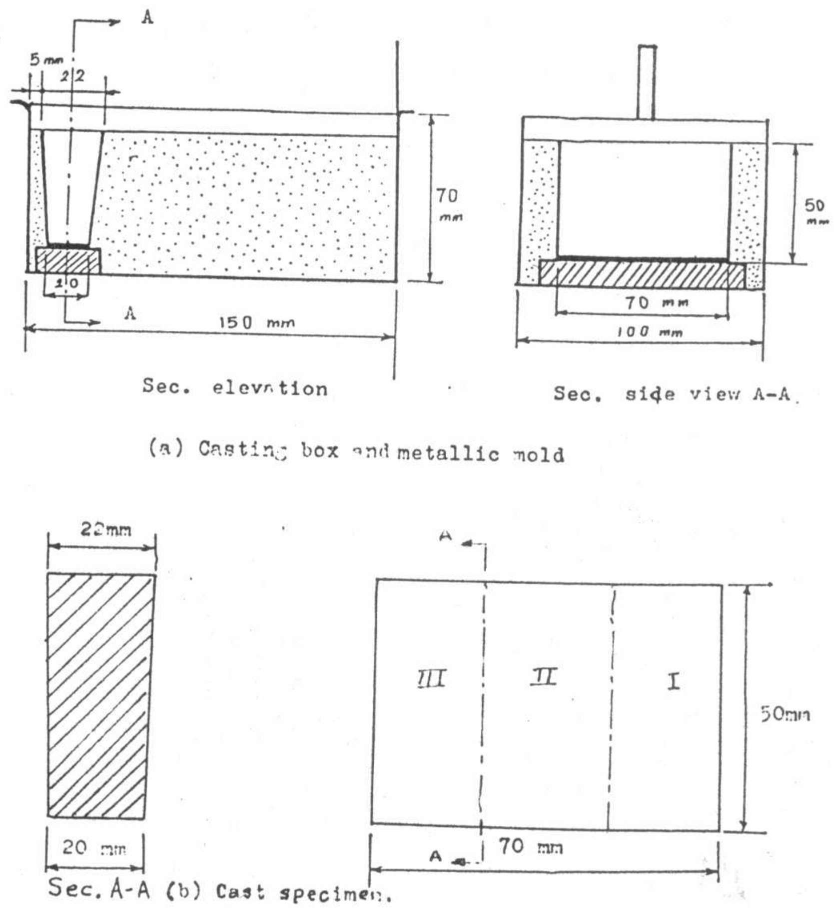
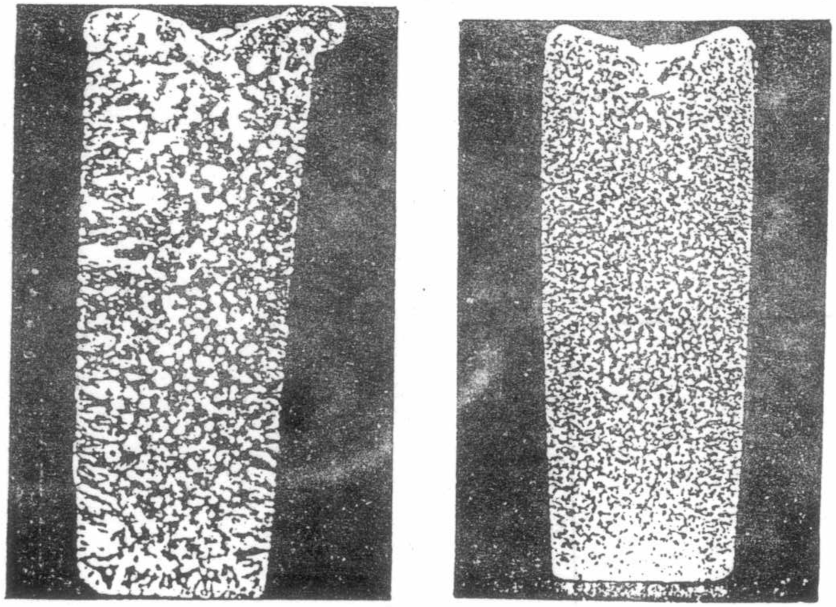


Fig.(3) The shape and dimensions of the cast specimens and the metallic mold .



(a) (b)

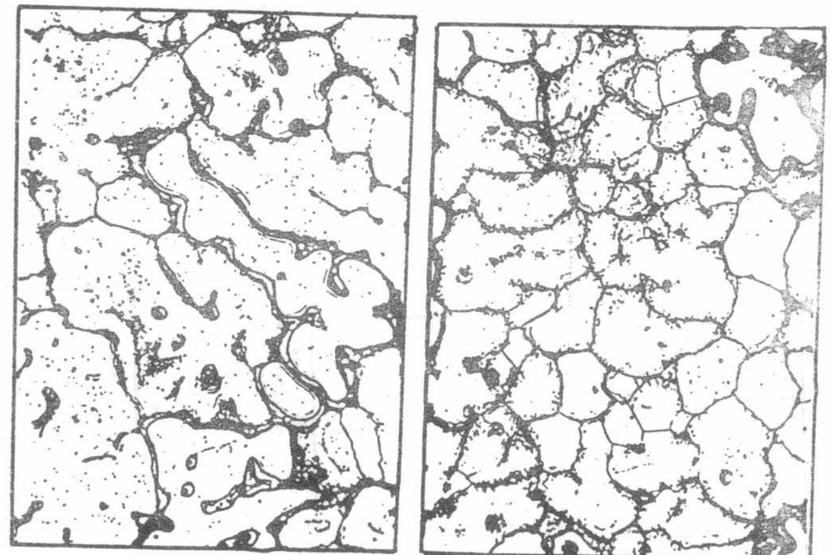
Macrostructure of Al-99.5% specimens

a) Without stirring force.

b) With stirring force

(Magnetic flux = 1860 G, I = 230A)

(Magnification 2 x)



(a) (b)

Microstructures of Al-4.3% Cu specimens

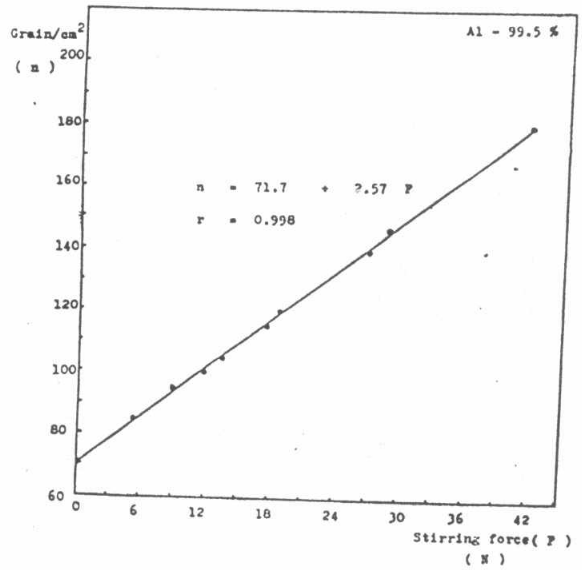
a) Without stirring force.

b) With stirring force

(Magnetic flux = 1860 G, I = 230 Amp.)

(Magnification 125 x)

Fig.(4) Effect of electromagnetic stirring on the structure of the Al 99.5% and the Al-4.3% Cu alloy .



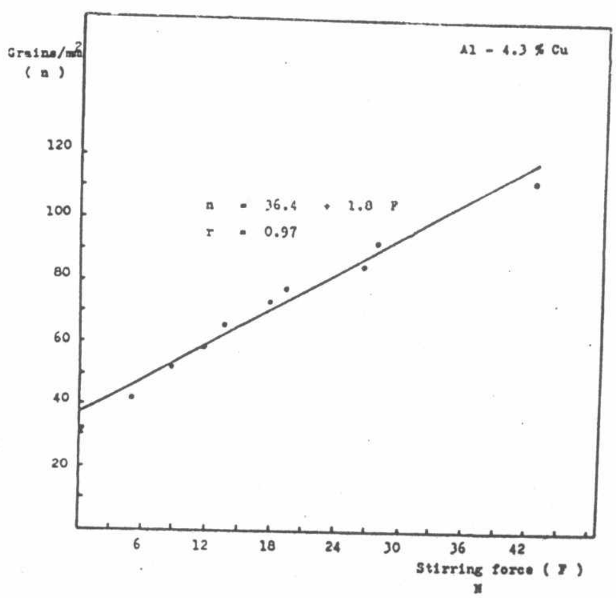


Fig. [illegible]
of grains per unit area (n) with
the stirring force for the Al-99.5%
and the Al-4.3% Cu alloy .

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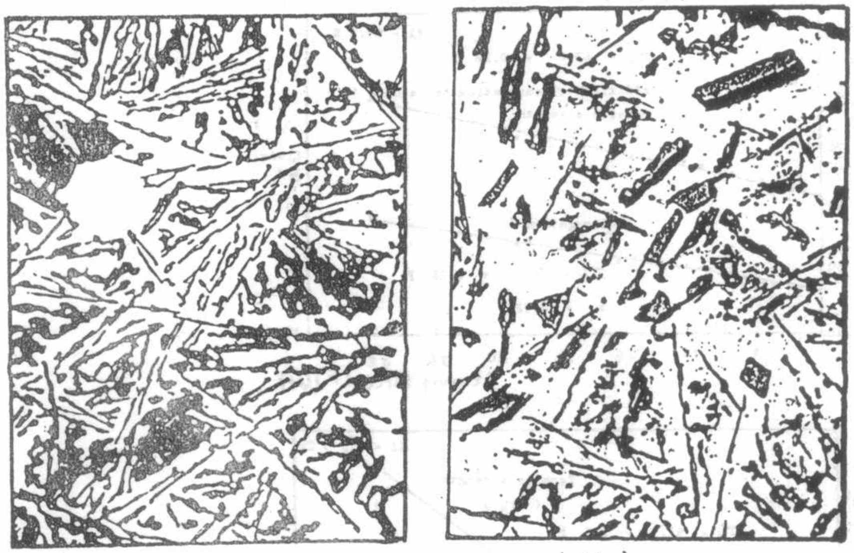

(i) (ii)

Fig.(6) Microstructures of Al-11.7% Si specimens i) Without stirring force . ii) With stirring force .
(Magnetic flux = 1860 G, I = 230 Amp .)
(Magnification 250 x)

(Magnification 250 x)

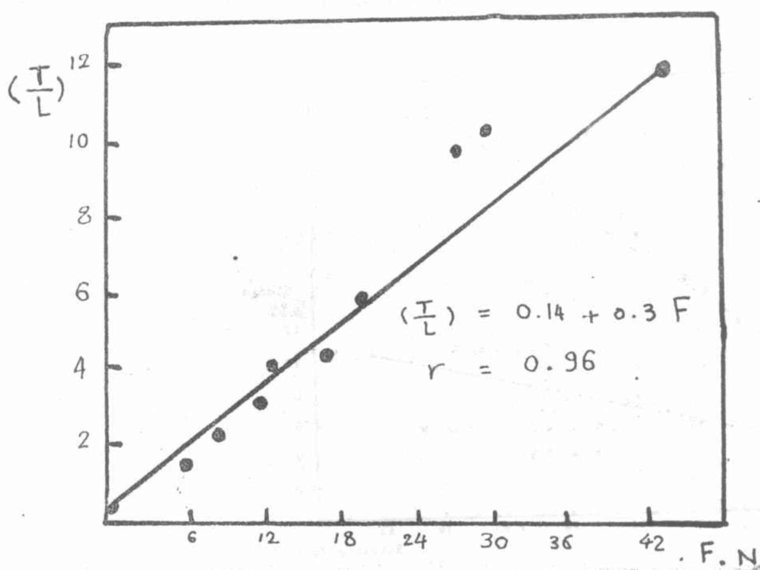

Fig.(7) Variation of the thickness to length ratio (T/L) with the stirring force (F) .

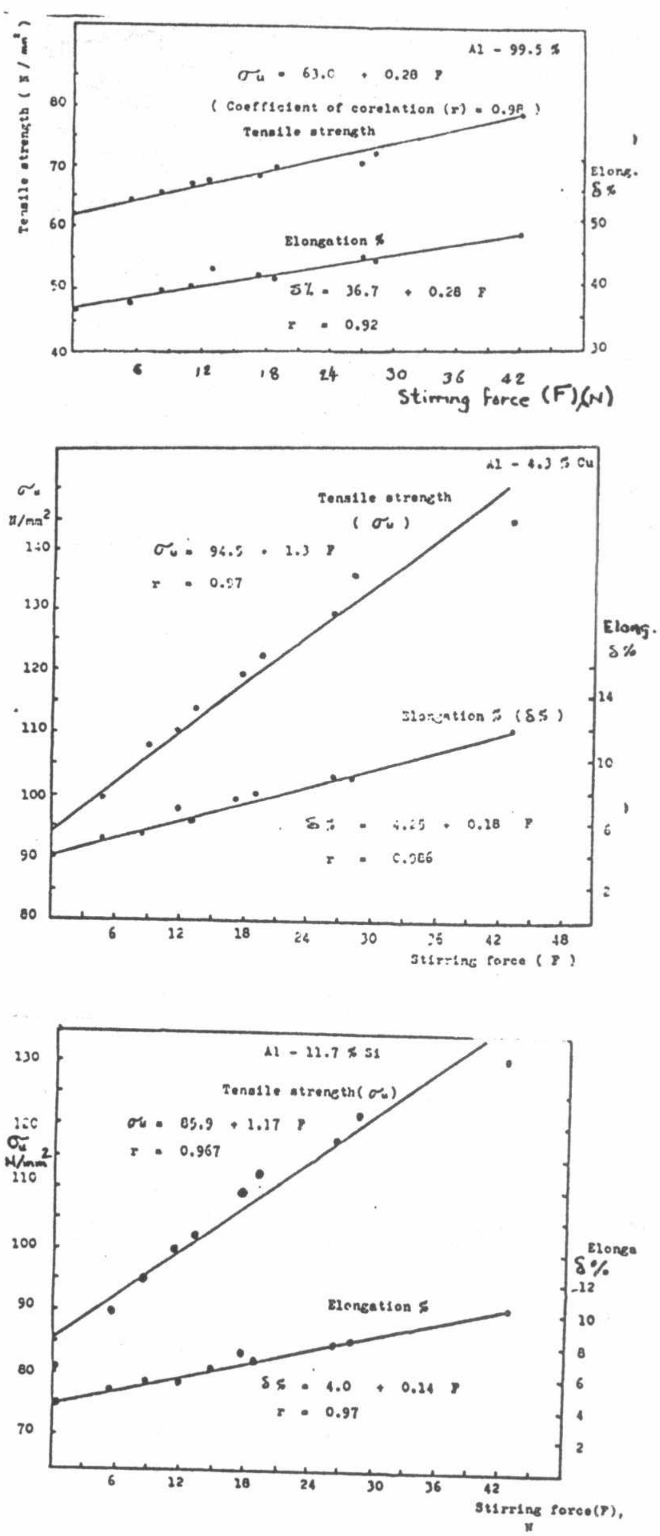

Fig.(8) Effect of electromagnetic stirring on the ultimate tensile strength and elongation% for the Al 99.5%, and the Al- 4.3 % Cu and the 11.7% Si alloys .

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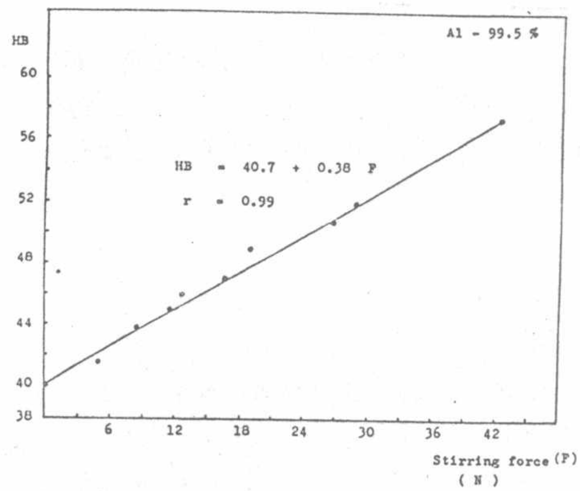

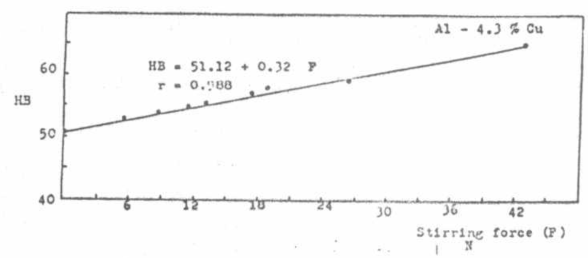

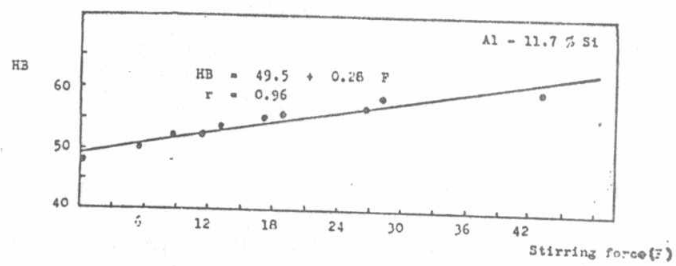

Fig.(9) Effect of electromagnetic stirring on hardness for the Al-99.5% , and the Al-4.3 % Cu and the Al-11.7% Si alloys .

III. Results and discussion

Fig.(4) shows the macrostructure of the ingots cast wit and without stirring for the commercial purity alu nium (99.5%) and the microstructure of samples of the ngots cast with and without stirring for the Al-4.3% Cu alloy .

s is shown ,a remarkable grain refining was obs rved to take place as a result of the application of electromagnetic stirring in the case of the two al ys .

The average number of grains per unit area (n) for the Al 99.5% and the Al-4.3% Cu alloy was measured and plotted against the stirring force (F) . These plots are shown in figure (5), where it is observed that (n) changes in a linear manner with (F) according to the following relationships :

$n = 71.7 + 2.57\ F$ grains $/mm^2$ .... (2)

(Coefficient of correlation = 0.98)

$n = 36.4 + 1.8\ F$ grains $/mm^2$ .... (3)

(Coefficient of correlation = 0.97)

In case of the Al-11.7% Si alloy , the silicon flakes were observed to transform from a needle like shape to a globular one by the application of the electromagnetic stirring as shown in the photomicrographs demonstraded in figure (6) .

The thickness and length of the silicon flakes were measured, and their average values were determined for the different conditions and the variation of their thickness to length ratio (T/L) with the stirring force was plotted in fig.(7) . Here also it is observed that the ratio (T/L) changes linearily with the stirring force (F) .

Figures (8) and (9) show the variation of the ultimate tensile strength (σ_u) , elongation percent(ε%), and hardness (HB) with the stirring force (F) for the Al 99.5% , and the Al-4.3% Cu and the Al-11.7% Si alloys.

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Due to the homogenity of the structure and grain refinement , the tensile strength (σ_u) the eleongation % (ε %) and the hardness (HB) were observed to increase in a linear manner with the stirring force .

The previous results indicate also that, the rate of increase of the tensile strength with the stirring force in the case of the Al-4.3% Cu and the Al-11.7% Si alloys is relatively higher than that in the case of Al 99.5% . This is most probably due to the difference in the solidification mechanisms in the three cases ; where for the Al-4.3% Cu alloy , solid solution is obtained, for the Al-11.7% Si alloy (eutectic) two phases structure is obtained, and for the Al 99.5% Solidification is mostly with columner smooth surface exogenous type that may have relatively lower response to stirring.

The observed effect of electromagnetic stirring on the structure is believed to be due to the production of fragements from the solidification front which then serve as nuclei for new grains in the process of crystal multiplication. This makes the dendrites appearing in the structure of the specimens cast without stirring become equiaxed and smaller when applying the electromagnetic field and direct current .

IV. Conclusions

The following conclusions can be drawn from this work :

1- The electromagnetic stirring in the range of the input power chosen in this work yielded an agreable structure homogenity combined with a remarkable grain refining and improvement of mechanical properties for the Al-99.5% , and the Al-4.3% Cu and Al-11.7% Si alloys .

2- The application of electromagnetic stirring during the solidification of the studied Al 99.5 and Al alloys was found to improve both metallurgical structure and mechanical properties in a linear manner.

3- The presence of alloying elements in aluminium in the form of solid-solution or eutectic results in a better response for grain refining by electromagnetic stirring .

References

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