

TEXTURE, COMPOSITION-SENSITIVE STRUCTURE AND MECHANICAL PROPERTIES OF Al-Cu AND Al-Zn ALLOY SYSTEM

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ABSTRACT

Binary alloys of Al-4%Cu and Al-4%Zn were inoculated with 0.5% Mg and V, respectively and tested for the presence of intermetallic phase and texture. The concentration of these dopants were varied by adding 0.1%, 0.5% and 1.0% by weight. Other inoculants investigated in a similar manner included Ca, Mn, Fe, Nb and Ta. The samples (alloys) produced were analysed for structural changes and mechanical properties.

The results showed a general trend of preferred orientation in the alloys. Deviation of the experimental angle of diffraction from the standard values was also observed. Attempts to establish a simple relationship between the observed mechanical properties and the composition-sensitive structure was not successful. This paper presents and discusses the results obtained in the investigation.

INTRODUCTION

Effective study of the relationship between composition and properties of some alloy systems can be undertaken by analysing the effect of small quantity of additives (inoculants) on their texture and microstructure. However, this method of comparison is meaningful if the casts are produced under identical solidification conditions. In carrying out the investigation, x-ray structural analysis technique is a very useful tool since it enables one to obtain such detailed information about any structural changes which occur. These changes could be due to alloy composition and conditions of solidification. Standardizing the solidification conditions makes it possible to attribute observable changes to compositional variations. One can therefore evaluate composition-sensitive structures (primitive cell size and microstress) and their influence on the properties of the alloy system.

In accordance with the function¹:

$$\beta = \frac{0.9 \lambda}{t \cos \theta}$$

where β = broadening of the diffraction line measured at half its maximum intensity (radians).

λ = Wavelength (Angstrom)

t = diameter of particles (Angstrom)

θ = Bragg angle,

the physical widening (β) of the diffraction lines (111) and (420) characterizes the Primitive cell size and residual microstress respectively.

The character of redistribution of linear intensity on the X-ray pattern permits one to study the presence or absence of preferentially oriented crystals of the α -phase, which results from solidification. The crystal axis coincides with the crystallographic direction (100) and the observed results were in line with earlier investigation^{2,3} on binary alloy systems. In Al-Si alloys, where the maternal solid solution has an FCC lattice, the texture of the ingot (100) matrix phase was observed without the presence of any preferred orientation². In any case, according to Roth³, the (100) texture arising from solidification in the column or crystal zone is characteristic of metals and alloys of the cubic class.

EXPERIMENTAL METHODS

The X-ray diffractometry technique was used in this work to investigate the phases present in the alloy system, the size of the primitive cells, micro-stress and the texture. The photographs were taken on the continuous regime of the diffractometer DRON-2 using the $\text{CuK}\alpha$ -rays; the pipe voltage was set at 24 KV, and the current was 18A. The rotational velocity of the counter during phase analysis was $1^\circ/\text{min}$. and the linear speed of tape displacement was 600 mm/hr. For the parameters of composition sensitive structure, photographs were taken at the rotation velocity of the counter of $2^\circ/\text{min}$. and the speed of the diagram length was 2400 mm/hr.

The specimens were made from Al-4% Cu and Al-4% Zn alloys. These alloys were further doped with elements of the IIA subgroup (Mg, Ca) and VA subgroup (V, Nb and Ta). For each inoculant chosen, 0.1%, 0.5% and 1.0% by weight were used. The melt of the parent alloys were produced and the desired quantity of the inoculant was added (to the melt) and cast. The cast alloy was then solutionized and quenched. Specimens were cut from the quenched alloys for observation of the longitudinal and cross-sectional sections. Sample preparations for diffractometry analysis conformed to the general specifications for various abrasive wheel grinding and polishing of Aluminium⁴. Chemical Milling (electropolishing) was used in the removal of deformed surface of the specimen. The electrolyte was made up of 1 part of nitric acid to 3 parts of methanol.

Phase analysis of the composition of the alloys was based on the recording of the diffraction from a few crystallographic planes typical of the lattices of the phases intended for identification. The position of the maximal diffraction angle for a given family of planes was fixed from the distribution of the intensities of the corresponding diffraction lines. To define the interplaner distances (d/n) the reference point was taken as the maximum intensity of the diffraction lines in the recordings of the diagram tape. The interpretation of results was conducted using the standard tables of interplaner distances⁵.

The composition-sensitive structures were determined from the changes in width of the diffraction lines (111) and (420) of the α -solid solution. Linear widening on the X-ray photographs when compared with the standard angle served as qualitative characteristic of changes which

took place in the structure of the alloys at the sub-microscopic level. The general width of the diffraction line is enhanced by the geometric conditions of photography, non-chromatic rays, and physical factors, i.e micro-stresses and primitive cells.

In order to obtain the physical widening, qualitative characteristics which define the parameters of composition sensitive structure, it was necessary to extract from the general width of the diffraction lines the effect imposed by the physical factors indicated above. The physical widening (β) of the diffraction lines was defined by the approximation method expressed as:

$$I = I_0 \text{Exp} (-ax^2)$$

This equation most accurately described the curves of distribution of the linear intensity of the experimental alloys and the standard. The standard was chosen as the alloy Al + 4%Zn + 0.5% Fe, preheated at a temperature of 270°C for 3 hours. Three specimens of each alloy were analyzed and the mean value was used in the calculations.

RESULTS AND DISCUSSION

The Standard Alloys

Diffractometry analysis of the parent alloy (Al-4%Cu) revealed diffraction lines of α -solid solution and lines of the secondary phase or θ -phase. The lines and their intensities for the above alloys are displayed in Table I(a). Also displayed in Table I(b) are values for the diffraction analysis of Al-4%Zn alloy which was the second parent alloy investigated. It can be observed that for the α -phase, the tabulated values of the diffraction represent an FCC lattice and the intensities as well as the associated angles of diffraction are closely approximated by the experimental values. The absence of significant detectable diffraction lines from the θ -phase (a BCC lattice) was observed in the Al-4% Cu alloy. This result could mean that the volume fraction of the θ -phase was not significant or that the lines underwent destructive interference. It should however be noted that the composition of Zinc in the Al-4%Zn alloy is below its solubility limit in Aluminium at room temperature⁶.

The similarity between the diffraction data obtained from the parent alloys (Al-4%Cu and Al-4%Zn) and tabulated values provide the basis for analysis of the effect of the inoculants.

Table 1(b)

Phase Constitution of Al-4% Zn Alloy

Alloy Al-4% Zn		
HKL d-phase	Tabulated intensity of diffraction, gradients	Experimental values of diffraction angle, gradients
111	30	19°20'
200	100	22°28'
220	10	32°40'
311	-	-
222	2	41°24'
400	15	19°58'
331	5	56°26'
420	6	58°33'
422	-	-

ADDITION OF INNOCULANT

(a) Cell Structure

It was decided that a third element Magnesium (Mg) or Vanadium (V) be added to the parent alloys considered above. Investigations were carried out using 0.5% of each element to inoculate the parent alloys. Shown in Tables II and III are results obtained for Al-4% Cu-0.5% Mg and Al-4%Cu - 0.5% V alloy respectively.

From table II (the diffraction pattern for Al-4%Cu-0.5% Mg is displayed) it is observed that new diffraction lines appeared compared to the results obtained for the parent alloy (Al-4%Cu). The measured angles of diffraction for these new lines were identical to tabulated values. It should be noted that some diffraction lines were however not observed in accordance with those indicated in the tabulated data. The absence of lines from (110), (002), (121), and (222) planes were noted. From Figure 1a-c, the presence of a second phase (θ) and preferred orientation is shown when inoculating Al-4%Cu alloy with 0.2% Mg and 0.2% V respectively. This confirms the source of the additional lines which appeared in the diffractograph. A similar observation was made with respect to the addition of 0.5% V to the parent alloy (see Table III). The addition of 0.5% Mg or 0.5% V to Al-4% Zn was investigated with the result as shown in Table IV. Both elements seem to affect the alloy in the same manner as was observed for the Al-4% Cu alloy.

Table 1(a)
Phase Constitution of Al-4% Cu Alloy

HKL d-phase	Tabulated Value		Experimental Value		HKL θ -phase	Tabulated Value		Experimental Value	
	Intensity of diffraction, %	Angle of diffraction, gradients	Intensity of diffraction, %	Angle of diffraction, gradients		Inter-planner distance 0	Angle of diffraction, gradients	Angle of diffraction, gradients	Angle of diffraction, gradients
111	100	19°15'	20	19°18'	111	4.284	10°21'	-	-
200	40	22°24'	100	22°26'	200	3.036	14°44'	-	-
220	30	32°33'	5	32°38'	002	2.437	18°26'	-	-
311	30	39°09'	6	39°14'	121	2.373	18°56'	-	-
222	7	41°16'	-	-	220	2.145	21°04'	21°02'	-
400	2	49°36'	10	49°44'	112	2.122	21°18'	-	-
331	4	56°06'	4	56°29'	130	1.918	23°42'	-	-
420	4	58°21'	4	58°30'	202	1.902	23°54'	23°50'	-
422	1	68°51'	-	-	22	1.612	28°32'	-	-

Table III
Phase Constitution of Alloys After Innoculation

HKL K-phase	Tabulated values		Experimental values		HKL θ-phase	Angle of Diffraction Degree	
	Intensity of diffraction, %	Angle of diffraction, degrees	Intensity of diffraction, %	Angle of diffraction, degree		Tabulated Values	Experimental Values
111	100	19°15'	100	19°18'	100	100°21'	-
200	40	22°24'	50	22°29'	200	14°44'	14°44'
220	30	32°33'	50	32°38'	002	18°26'	-
311	30	39°09'	45	39°17'	121	18°56'	-
222	7	41°16'	15	41°30'	220	21°18'	21°04'
400	2	49°36'	3	49°51'	112	21°18'	21°18'
331	4	56°06'	2	56°30'	130	23°42'	23°46'
420	4	58°21'	4	58°34'	202	23°54'	23°52'
422	1	68°51'	1	69°09'	222	28°32'	-

Table II

Phase Constitution After Innoculation

HKL K-phase	Tabulated Value		Experimental Values		HKL θ-phase	Angle of Diffraction, Degree	
	Intensity of diffraction, %	Angle of diffraction, degree	Intensity of diffraction, %	Angle of diffraction, degree		Tabulated Values	Experimental Values
111	100	19°15'	100	19°16'	100	100°21'	-
200	40	22°24'	70	22°28'	200	14°44'	14°42'
220	30	32°33'	30	32°36'	002	18°26'	-
311	30	39°09'	40	39°16'	121	18°56'	-
222	7	41°16'	10	41°24'	220	21°18'	21°02'
400	2	49°36'	5	49°46'	112	21°18'	21°18'
331	4	56°06'	4	56°24'	130	23°42'	23°43'
420	4	58°21'	4	58°30'	202	23°54'	23°52'
422	1	68°51'	2	69°26'	222	28°32'	-

Alloy Al-4%Zn - 0.5%Mg				Alloy Al-4%Zn - 0.5%V			
HKL α -phase	Tabulated values Intensity of diffraction, %	Experimental values Angle of diffraction, degree	HKL α -phase	Tabulated values Intensity of diffraction, %	Experimental values Angle of diffraction, degree		
111	100	19°21'	111	100	19°22'		
200	60	22°29'	200	70	22°32'		
220	40	32°40'	220	30	32°44'		
311	25	39°16'	311	40	39°16'		
222	8	41°24'	222	10	41°28'		
400	4	50°00'	400	5	50°04'		
331	6	56°26'	331	4	56°28'		
420	3	58°35'	420	4	58°35'		
422	1	69°06'	422	2	69°12'		

Table IV

The widening effect seems to decrease with the elements (innoculant) according to the following order Mn>Fe>Ca>Mg. Concentration of the innoculant above or below 0.5% resulted in less widening and lower values of β_{420} . Except calcium (Ca), increased dosage of the innoculant did not seem to increase the tensile strength of the resultant alloy.

It is interesting to note that maximum widening did not occur at 0.5% dosage in the Al-4%Zn alloy (See Figure III). In this alloy, widening and tensile strength increased with increase in Mg concentration. The addition of Fe showed decreasing widening, β_{420} with increase in dosage while the strength showed direct relationship with the quantity of Fe added. No widening was observed for 0.1% Ca (Fig. III); 0.1Mg and 1.0% Fe (Fig. II).

The effect of innoculant on the hardness of the alloys appears in Figure IV. Increase in hardness is observed with addition of Mg and Fe to either Al-4%Cu or Al-4%Zn alloy while Magnesium addition gave the largest increase in hardness values than the parent alloy for dosages lower than 0.5%. However, the general trend is that the hardness increases with increase in dosage.

Elongation (δ) of the alloys decreases with addition of the innoculants except in Al-4%Zn-0.5%Mg; Al-4%Zn-0.5%Mn, Al-4%Zn-0.1%Fe and Al-4%Zn-1.0%Fe which actually show increase.

Addition of elements of the VA subgroup (V, Nb, and Ta) into the melt showed similar effect as those discussed above. Additives in quantities between 0.1% and 1.0% lead to structural distortion as evidenced by addition of 0.5% to both parent alloys (see Table III and IV). In any case, changes in phase constitution of the alloys after inoculation with elements of the VA subgroup were not observed.

CONCLUSION

Significant changes in structure and properties of Al-4%Cu and Al-4%Zn alloys can be brought about by the addition of small amounts of some innoculants to the melt. These additions cause physical widening of the interference lines (111 and 420) due to cell distortion and micro-stresses. Increase in strength and decrease in plasticity were observed in alloys inoculated with 0.1%, 0.5% and 1.0% of the third element. The lack of simple correlation between the observed physical properties, types and quantity of innoculant suggests a more complex controlling factor in the structure - property relationship.

(b) Physical Properties:

More tests were carried out to determine the effect of innoculant additions on the properties of the alloys produced. Table V displays the data collected on a series of alloys inoculated with 0.1, 0.5, and 1.0% of selected elements. Parameters measured include: elongation (δ), tensile strength (σ), hardness (HB), and widening factors (β_{111} and β_{420}). Data from Table V were used to construct Figures II, III, and IV. From Figure II, the widening of the diffraction line from (420) planes was maximum at 0.5% addition of every innoculant investigated. It was also observed that Manganese causes the largest widening.

TABLE V

Mechanical Properties and Widening of Diffraction Lines

Alloy	$\delta, \%$	σ, MPa	$H_{0.2}, \text{MPa}$	β_{111}, mm	β_{20}, mm
Al-Cu	7	140	450	-	-
Al-4%Cu - 0.1%Mg	1.7	91	536	0.9	-
Al-4%Cu - 0.5%Mg	-	103	644	1.0	1.8
Al-4%Cu - 1.0%Mg	0.3	99	720	0.6	1.6
Al-4%Cu - 0.1%Ca	6.3	72	396	1.1	1.7
Al-4%Cu - 0.5%Ca	5.6	123	372	0.5	2.2
Al-4%Cu - 1.0%Ca	5.7	152	396	0.8	1.1
Al-4%Cu - 0.1%Mn	4.7	113	449	0.7	2.0
Al-4%Cu - 0.5%Mn	4.6	106	624	0.6	2.0
Al-4%Cu - 1.0%Mn	1.5	85	406	0.5	2.2
Al-4%Cu - 0.1%Fe	4.9	119	469	0.8	1.9
Al-4%Cu - 0.5%Fe	4.9	143	450	0.9	2.2
Al-4%Cu - 1.0%Fe	4.2	120	456	0.5	-
Al-4%Zn - 0.1%Mg	10.8	67	223	0.5	1.7
Al-4%Zn - 0.5%Mg	10.5	116	325	0.6	1.0
Al-4%Zn - 1.0%Mg	3.4	165	476	0.5	2.3
Al-4%Zn - 0.1%Ca	6.1	59	228	0.7	-
Al-4%Zn - 0.5%Ca	6.0	52	221	0.5	1.9
Al-4%Zn - 1.0%Ca	15.0	68	237	0.5	1.9
Al-4%Zn - 0.1%Mn	6.8	64	124	0.4	0.6
Al-4%Zn - 0.5%Mn	16.1	95	228	1.0	1.0
Al-4%Zn - 1.0%Mn	15.2	79	274	0.4	0.9
Al-4%Zn - 0.1%Fe	10.6	92	228	0.6	1.3
Al-4%Zn - 0.5%Fe	12.3	96	268	0.2	1.0
Al-4%Zn - 1.0%Fe	21.9	106	262	0.4	0.6
Al-4%Zn	16.0	80	230	-	-

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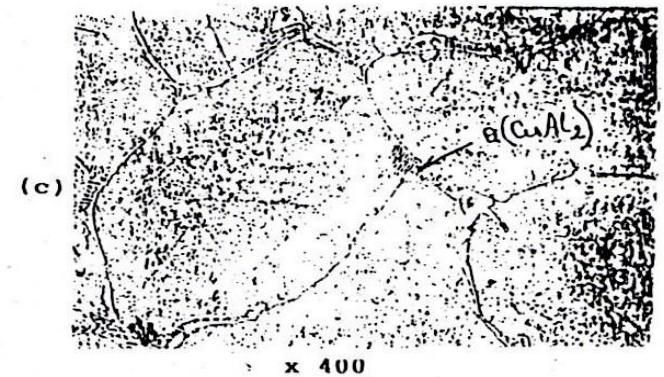
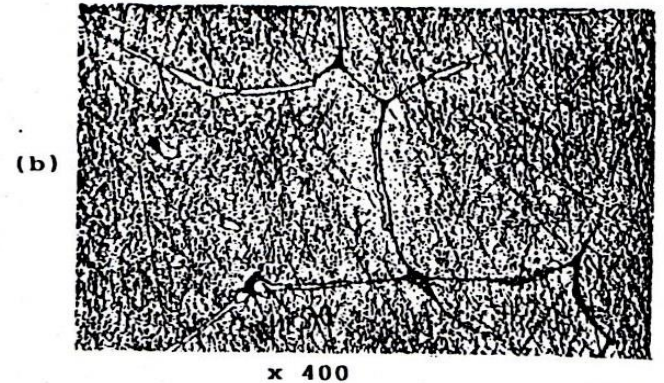
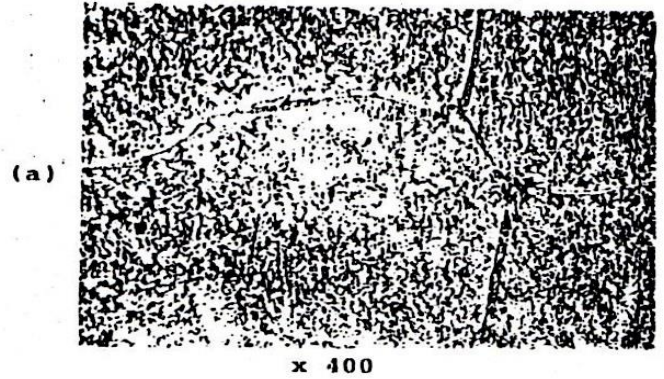


Fig. 1: Microstructure of Al-4%Cu (a) modified with (b) 0.2%Mg and (c) 0.2%V

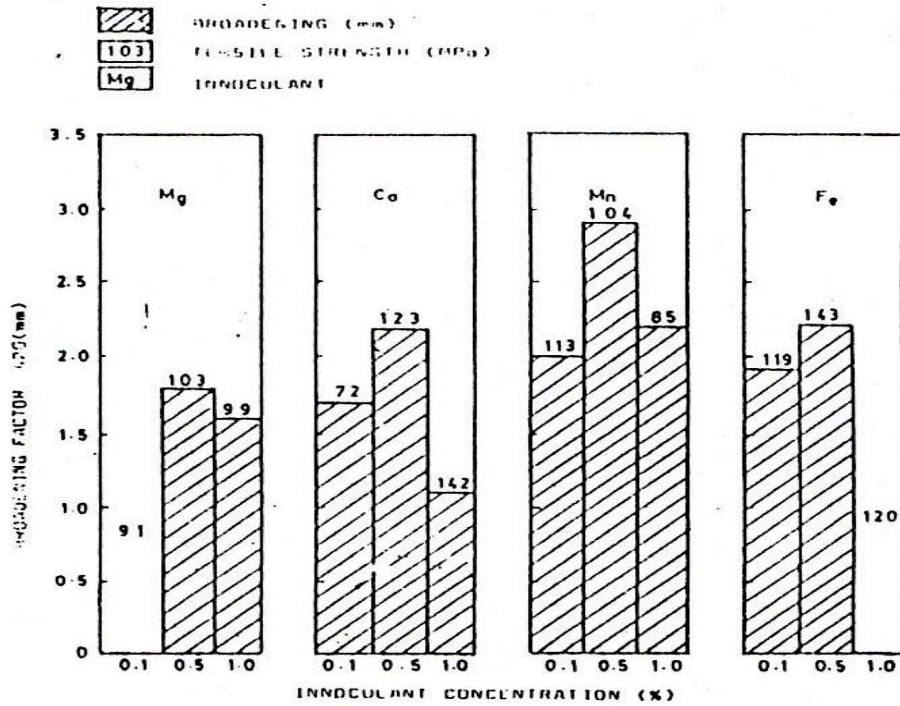


FIG. 110: INTERDEPENDENCE OF BROADENING FACTOR, INOCULANT CONCENTRATION AND TENSILE STRENGTH OF INOCULATED Al-4% Zn ALLOY

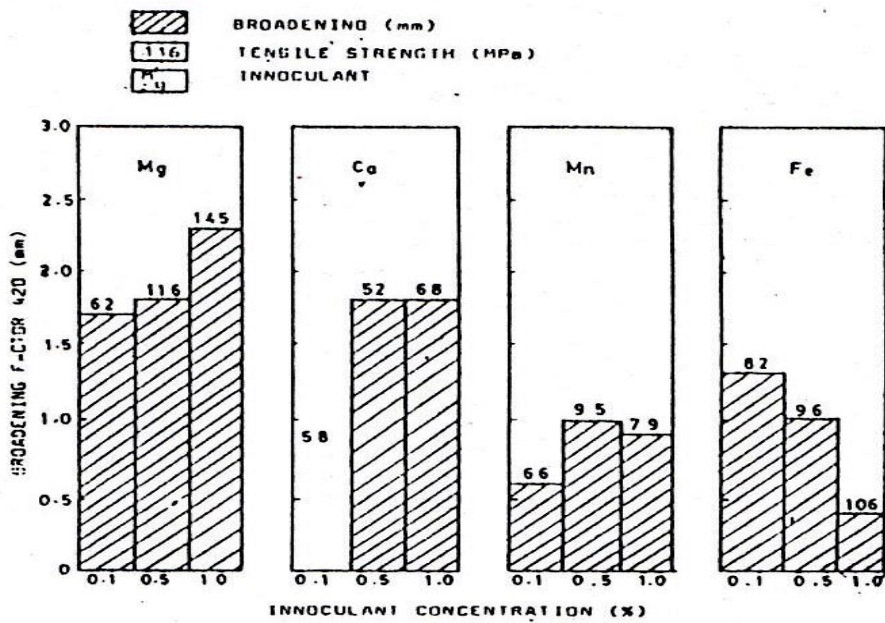
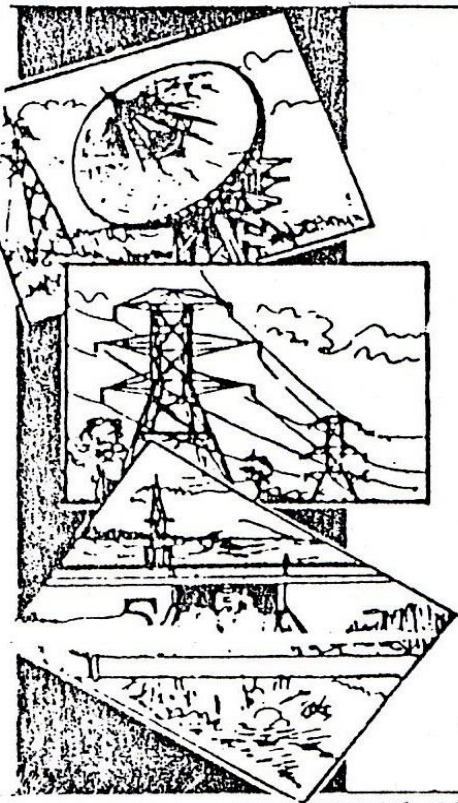
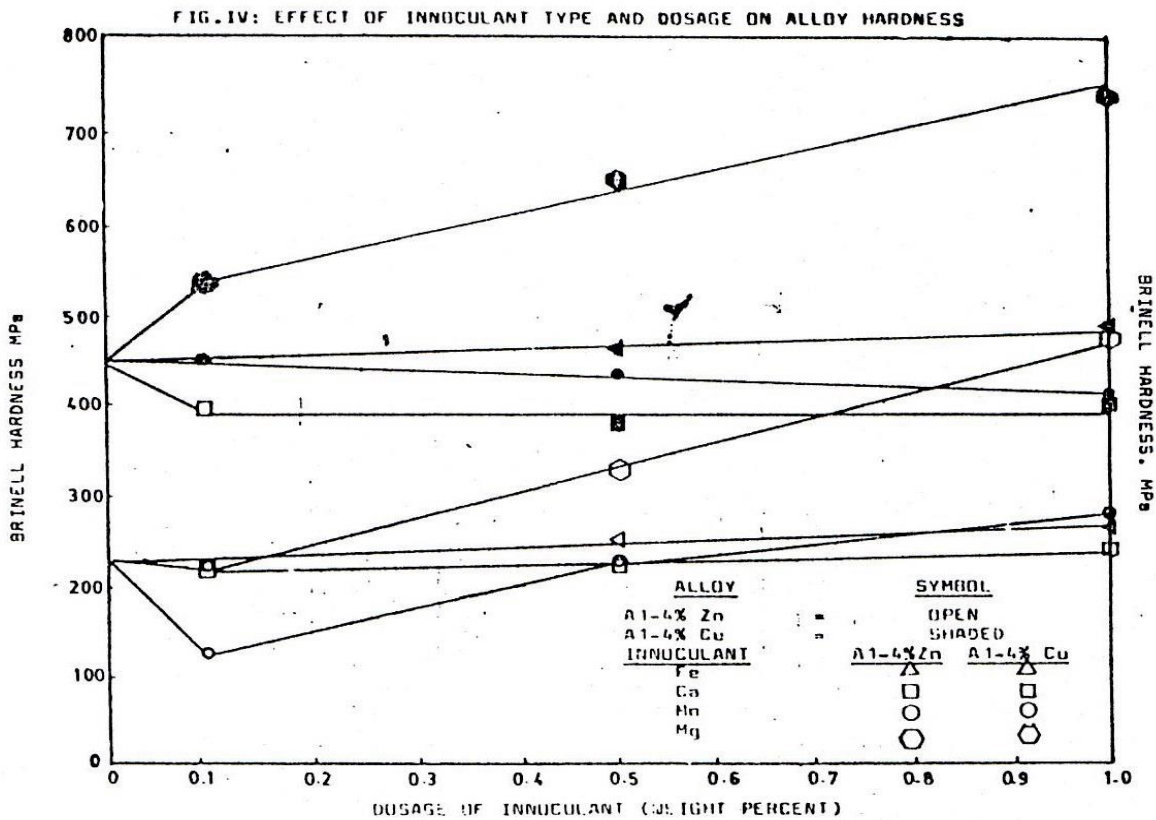


FIG. 111: INTERDEPENDENCE OF BROADENING FACTOR, INOCULANT CONCENTRATION AND TENSILE STRENGTH OF INOCULATED Al-4% Zn ALLOYS.



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