To Study the Role of Process Parameters and Minor Additions on Microstructure and Mechanical Properties of Aluminum Alloy

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Abstract

Aluminum — Silicon casting alloys are the most versatile of all foundry alloys because of their unique combination of properties which include good castability, machinability and low density with optimum mechanical properties and higher wear resistance. These properties make cast Al-Si alloys eligible for widely used in automobile, aerospace and general engineering industry. Properties of Al-Si alloys are predominantly influenced by the various factors such as microstructure, presence of alloying element, cooling or solidification rate, heat treatment and effect of alloying elements.

Al-Si alloys are classified as hypoeutectic (up to 10% Si), eutectic (11-12% Si) and hypereutectic (>12% Si). Hypoeutectic aluminum—silicon alloys have a - aluminum grains along with eutectic. Hypereutectic aluminum—silicon alloys have primary silicon phase together with the eutectic. Mechanical properties of Al-Si alloys depend mainly upon the size, form and distribution of silicon particles. These second phase silicon particles affect the toughness and ductility: If silicon particles (both primary and eutectic in case of hyper alloys and eutectic, in case of hypo alloys) are modified mechanical properties show appreciable improvement and their machining becomes easier.

The grain size of a primary aluminum is controlled by the addition of heterogeneous nuclei to the melt as aluminum—titanium or aluminum- titanium— boron (titanium 3-5%). Grain size varies from 100 — 500 tm. Cells contained within the dendrite structure correspond to the dimensions separating the arm of primary dendrites and are controlled by solidification rate for given composition. Another factor is the presence of second phase particles, which segregate at inter—dendrite spaces. More segregation of inclusion or second phase particles, greater than the dendrite—arm spacing so coarsens the structure. Presence of Mg script like second phase makes the alloy more brittle and prone to the cracking, therefore, Mg is added up to 1.5% in Al—Si alloys. Strontium treatment has some positive effect on reduction of such phases during solidification of these alloys.

INTRODUCTION

1. Development of Cast Alloys

The alloys developed for the investigation are (i) Al-12Si-1.12Cu-1.1Ni-1.0Mg and (ii) Al-13Si-1.2Cu-1.0Ni-1.0Mg.

Experimental Alloys were prepared by careful melting and dilution of alloying elements such as Si, Mg, Ni, Cu in combination with aluminium of 99.99% purity and heavy scrap in the medium frequency induction furnace. The specifications of induction furnace are as follows:

(a) Main frequency – 50 Hz
(b) Alumina Lining
(c) Core less type
(d) Hydraulic lifting
(e) 600 KW rating
(f) 600 Kg/Hr melt rate
(g) Copper water cooled coils
(h) Capacity 2 tons
(i) Tapping temperature = 850^{o} C
(j) Charging sequence = Al & Heavy scrap, then semi liquid charged Si & then other alloying element.

Furnace was covered at the top to avoid oxidation and gas pick up. Necessary allowances for melting losses were also taken into account in computation of charges. The nominal compositions of two alloys are given in Table ….. All the compositions have been expressed in wt %.

Table: Nominal Composition of Alloys

Sr No	Code	Si	Cu	Ni	Mg	Fe	Al
1.	A	12.00	1.12	1.1	1.0	0.20	Balance
2.	B	13.00	1.20	1.0	1.0	0.25	Balance

After melting, the melt was transferred to electrically operated holding furnace having silicon carbide crucible and the covered with cover flux to avoid oxidation. After through dross cleaning, Cu-8% P alloy was added(76 ppm and 126 ppm) at 870^{o} C. The melt was given flux treatment and rotary degassing (300

rpm) was performed with nitrogen and argon gas for alloy- A for 5 minutes by each gas. For Alloy - B degassing was carried out by nitrogen gas for 10 minutes. The melt so treated was poured at 730° C and 770° C temperature into metallic mould (37 mm x 37 mm x 300 mm). A filter was kept at the top of metallic mould to trap inclusions and dross particles.

Summary of melting treatment parameters are given in Table….. and Table……

Table 1: Summary of Melt Treatment Parameters for Al- 12 Si-1.12Cu-1.1Ni-1.0Mg Alloy

S.No.	Alloys Code	Rotary degassing (300 rpm)	% P (ppm)	Pouring Temp. (°C)
1.	A-1	Without degassing	76	730
2.	A-2	N_2 + Ar (5 +5 Min)	76	730
3.	A-3	N_2 + Ar (5 +5 Min)	126	730
4.	A-4	N_2 + Ar (5 +5 Min)	76	770
5.	A-5	N_2 + Ar (5 +5 Min)	126	770

Table 2: Summary of Melt Treatment Parameters for Al- 13 Si-1.20Cu-1.0Ni-1.0Mg Alloy

S.No.	Alloys Code	Rotary degassing (300 rpm)	% P (ppm)	Pouring Temp. (°C)
1.	B-1	Without degassing	76	730
2.	B-2	N_2 (10 Min)	76	730
3.	B-3	N_2 (10 Min)	126	730
4.	B-4	N_2 (10 Min)	76	770
5.	B-5	N_2 (10 Min)	126	770

2. Metallography

Samples for microstructure studies were cut from ingot castings. They were polished on a series of emery papers from 1/0 to 4/0 grade and finally on sylvet cloth using diamond

paste. Polished samples were etched with Keller's reagent. All possible precautions were taken during polishing and etching of samples. Optical microscope was used for examination of microstructure of the samples.

3. Mechanical Properties

Samples required for mechanical properties tests (hardness, UTS and % elongation) were machined from the cast alloys. Each mechanical test was performed by three samples, after which average value were recorded.

4. Hardness Measurement

The samples for hardness measurement first polished on emery papers upto 4/0 grade. So as to obtain fine polished surface. Hardness measurement at different locations over the entire face were taken on Rockwell Hardness tester on R_B scale. A small load, called the minor load, of 10 Kg is applied by raising the anvil further upto a definite position of dial gauge. The final (or major) load (100 Kg) is then applied by releasing a system of levers, which forces the indenter down in to the surface of the specimen. Before the reading of the gauge is taken, then major load is removed.

5. Tensile Strength

Tensile test were carried out by Housefield Tensometer. The sample dimension is shown in fig. . The ultimate tensile stress (UTS) and % elongation determined from the sample test.

EXPERIMENTAL RESULT

1. Solidification and Grain Refinement

The LM-13 alloys represent a complex version of the binary Al-Si eutectic. This introduces difference in its solidification pattern, although its behavior is greatly similar to that of the binary eutectic. It is usually hypoeutectic and it contains various alloying and impurity elements. The driving force for solidification is supplied by undercooling. The most favorable sites for eutectic nucleation are in the area of liquid between the aluminium dendrites or grains, where the liquid is rich in silicon. Solidification begins at nucleating point in the melt and after nucleation, the solid Al and Si phases grows radially side by side to form eutectic cells. During the growth of the eutectic cells, the remaining liquid becomes progressively richer in solute elements since they are rejected by both the aluminium and the silicon and these form complex

phases which at lower temperature, nucleate on the eutectic already present. Impurities remain in the liquid and are pushed in the solid liquid interface, finally solidifying around the eutectic cells.

Growth of these constituents is slow and a coarse intermetallic network form throughout the structure to complete the solidification sequence. Gray silicon particles are presents in a composition and temperature under equilibrium condition, two solid phases separate from a single liquid. The faster cooling rate the greater the degree of undercooling before the ousted of nucleation, when nucleation does takes place, growth is faster and a finally branched silicon results.

In these alloys the silicon precipitates on solidification in large irregularly shaped and distributed crystals which have an adverse effect on the mechanical properties. These large primary silicon crystals have, therefore, to be refined in order to obtain a fine and more uniformly distributed structure to confer maximum physical properties. These alloys need special treatment with a grain refining agent which has a similar crystal structure and lattice spacing as silicon. It has been found that aluminium phosphide fulfils these

requirements very well and that excellent grain refining can be obtained.

In industrial practice, nucleating agents are added to promote heterogeneous nucleation. Titanium and boron are added to aluminium alloy melts, P to refine silicon in hypereutectic Al-Si alloy. AIP compound forms when P is added to aluminium. AIP has lattice constant 5.45A° and higher melting temperature than Si and therefore nucleates the later, which has a lattice constant 5.42 A°. The lattice parameter of AIP is close to that of aluminium, suggesting a small contact angle during heterogeneous nucleation, when closed packed planes of two crystals can have a one to one correspondence of atoms at the interface. This effectively lowers the nucleation barrier, increase the nucleation rate and produce a fine grain size in the casting. In addition to lowering the contact angle by good lattice matching, a successful nucleation agent should be stable in the molten metal and posses a large area and roughness. If melt is heated to 870℃ and then brought down to pouring temperature, grain refinement is obtained. This is due to deactivation of oxides and other harmful impurities which floats out and allow higher super cooling for solidification.

It is to be noted that latent heat of fusion of silicon is

337 cal/gm and that of aluminium is 93 cal/gm and this helps the alloy in having high fluidity. Rapid cooling gives rise to uniform fine structure.

However, this is difficult to achieve in casting having different section thickness. Therefore, for achieving uniform refinement of casting, small amount of various elements such as Na, Sr and P are added. When P is added in the melt numerous nucleation sites are created. This refines eutectic and primary silicon. Phosphorus addition has marked effect on the distribution and form of primary silicon phase. It is reported that 0.0015% to 0.03% P are effective in achieving the retained structure.

2. Microstructure

Microstructures for alloy-A are shown from Fig. to Fig. under different conditions. Microstructures for alloy-B are shown from Fig. 4 7 to Fig. 4.10 under different conditions. It is clear from the micrographs that silicon mainly precipitates in the form of needles within the Al-Si eutectic alongwith dispersed Mg_2Si phase. The microstructures also reveal primary crystals of silicon. It is observed that phosphorus brings about the refinement of the primary silicon and simultaneous refines the eutectic to some extent so silicon plates in eutectic

become shorter and wider. It is also observed from the micrographs that aluminium dendrites are found in bundle and the eutectic Si is observed in the interdendrite channels.

It is apparent from the microstructure that from raising the phosphorus content from 76ppm to 126ppm, the number of heterogeneous nucleating sites are increased which can nucleate more number of primary silicon particles, finer in size. When melt is poured at higher temperature (770℃) it is observed that primary silicon of finer size is obtained. The reason being that at higher temperature numerous active AIP heterogeneous particles are available which nucleate primary silicon. It can be inferred that 126ppm phosphorous addition at 770℃ pouring temperature shows better refinement.

LM-13 alloy is hypoeutectic in nature. In fact the observed microstructure is not unexpected keeping in view the asymmetric nature of the Al-Si phase diagram. Phosphorus, when added at an optimum level (0.03% P), form AIP which can act as a substrate for the nucleation of primary Si particles from the melt of an eutectic composition. Since Si particles nucleate and grow first, the remaining liquid becomes depleted in Si. The liquid thus behaves like hypoeutectic. Al-Si alloys consisting of alpha Aluminium dendrites and eutectic Silicon.

There is better refinement of primary silicon at 126 ppm phosphorous in comparison to when 76 ppm phosphorous added (Fig. 4.3) under similar conditions. It is also observed that same amount of P

when added at higher temperature, is more effective grain refiner as is evident from Fig 4.3 and Fig.4.5. Similar tends are also observed in case of alloy-B under different conditions.

3. Effect of Foundry Variables

It is observed that with variation in phosphorus additions and pouring temperature (730℃ and 770℃) AIP as nucleant caused change in refinement of Si particles. At high pouring temperature AIP was more active and provided more number of sites for heterogeneous nucleation. This may be the reason for finer silicon particles at higher temperature. At higher temperatures deactivation of oxides and other harmful impurities takes place which floats out and allow higher super cooling for solidification. Inert gas degassing employed seems to reactivate AIP nuclei presumably by resuspension in addition to hydrogen removal. It is observed that nitrogen and argon combined degassing was equally effective as carried out by argon alone.

4. Effect of Composition

Increasing the Si content from 12 to 13% showed marginal improvement in hardness at the expense of tensile strength.

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5. Mechanical Properties

It is observed from the table 4.1 and 4.2 that hardness in virtually independent of the degree of refinement. However, phosphorus addition has shown marked improvement in tensile strength values. It may be *seen from* Table *4.1 that the cast* alloy *has tensile* strength *20.5 Kg/mm*^{2} while after phosphorus addition (126 ppm at 770°C) tensile strength has *increased to 27.0 Kg/mm*^{2} (Alloy A-5). *The reason for high* tensile strength may be attributed to better refinement of silicon particles at 770°C. Similarly, it may be seen for Alloy-B (Table 4.2). Alloy B-5 (pouring at 770°C) showed maximum tensile strength at 126 ppm phosphorus addition. However, the tensile strength of alloy A-5 was higher than that of alloy B-5. This is due to difference in silicon percentage. A slight improvement in percentage elongation is also observed:

Table 1: Mechanical properties of Al- 12 Si- 1.12 Cu- 1.1 Ni- 1.0 Mg Alloy

S.No.	Alloys Code	Tensile Strength(Kg/mm^2)	% (Elongation)	Hardness (RB)
1.	A-1	20.5	0.52	49
2.	A-2	21.5	0.98	50
3.	A-3	22.20	1.26	52
4.	A-4	23.8	1.00	50
5.	A-5	27.00	1.00	50

Table 2: Mechanical properties of Al- 13 Si- 1.20 Cu- 1.0 Ni- 1.0 Mg Alloy

S.No.	Alloys Code	Tensile Strength (Kg/mm^2)	% (Elongation)	Hardness (RB)
1.	B-1	19.5	0.51	54
2.	B-2	21.9	0.76	53
3.	B-3	21.56	0.78	55
4.	B-4	21.02	0.76	54
5.	B-5	25.20	0.51	52

CONCLUSIONS

Following conclusions are drawn from the present investigation:

1. Phosphorus is an effective primary silicon refiner and up to some extent also refines eutectic silicon.

Tensile strength improves with addition of phosphorus. 126 ppm addition of phosphorus at 770°C pouring temperature showed maximum tensile strength.

3. Hardness is virtually independent of the degrees of refinement.

4. There is slight improved in elongation i.e. up to 1% by addition of phosphorous.

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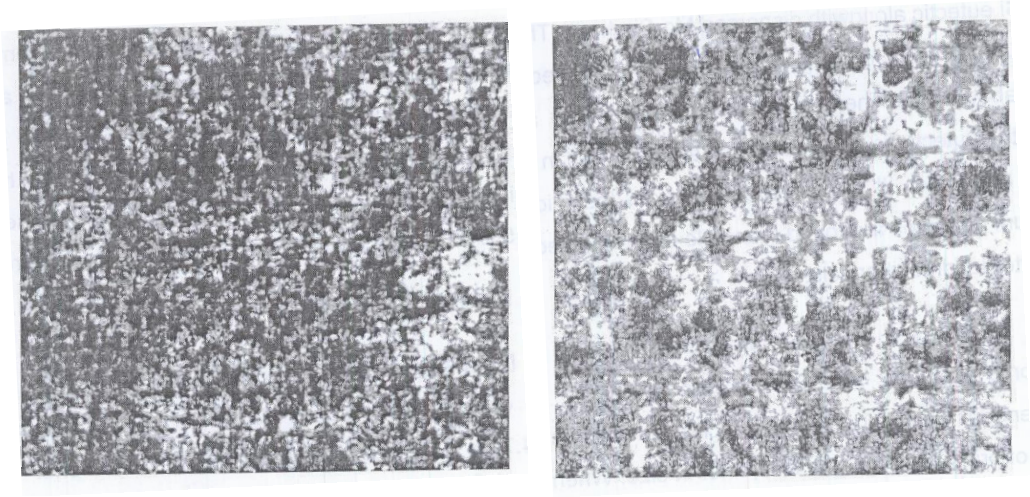
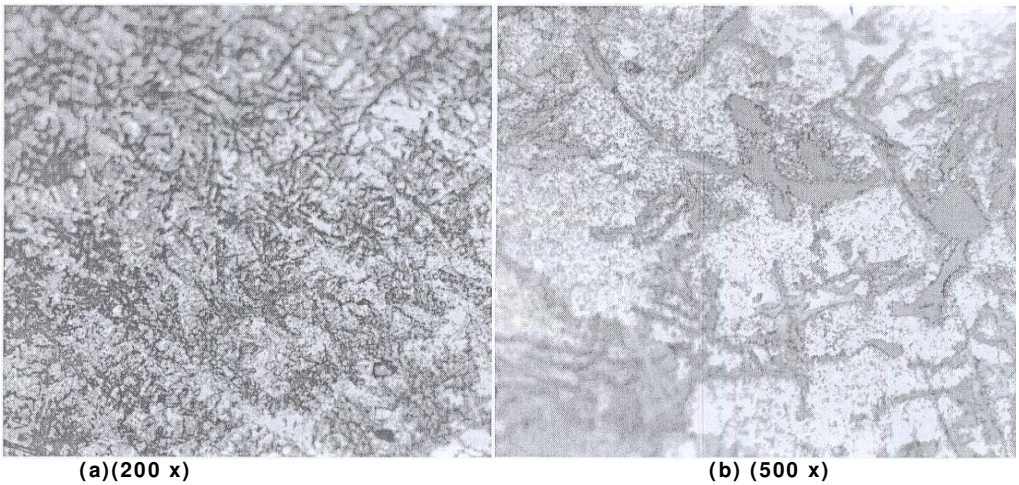


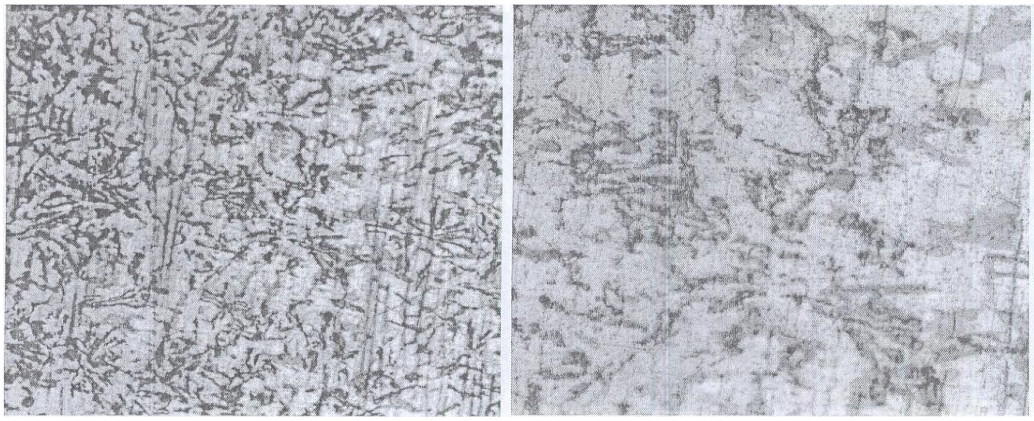
(a) (200 x) (b) (500 x)

Fig.1 Optical Micrographs of Alloy A-1 Without Degassing (76 ppm P, Pouring Temperature 730°C)



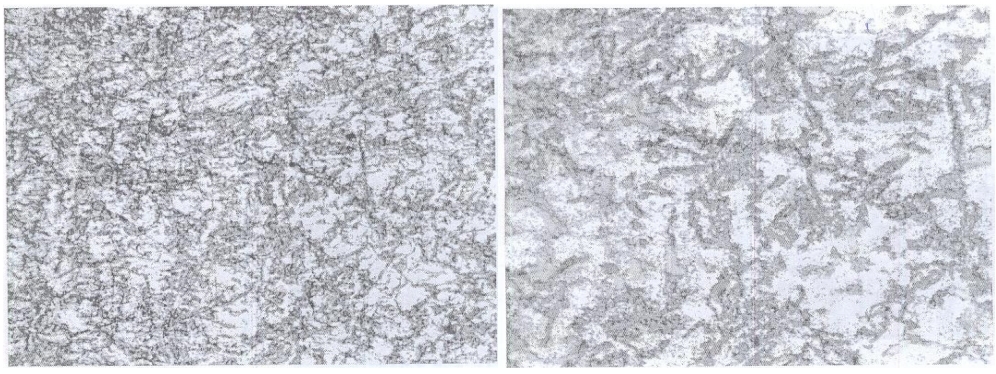
(a)(200 x) (b) (500 x)

Fig.2 Optical Micrographs of Alloy A-2 at Different Magnifications (76 ppm P, Pouring Temperature 730°C)



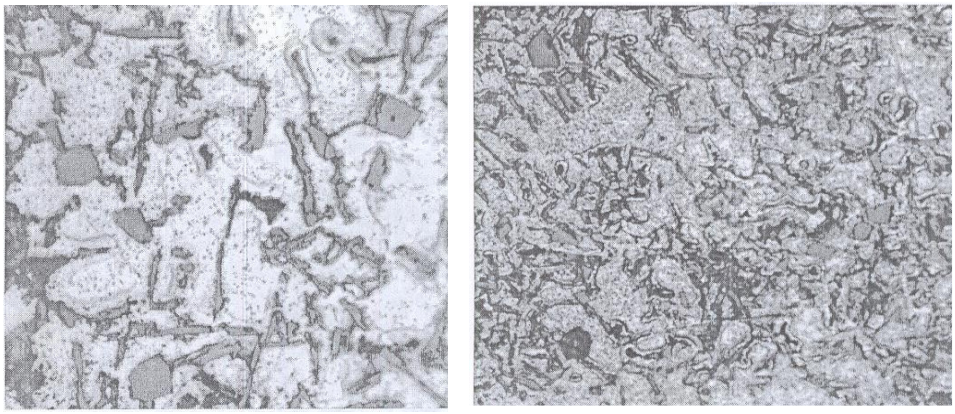
(a)(200 x) (b) (500 x)

Fig.3 Optical Micrographs of Alloy A-3 at Different Magnifications (126 ppm P, Pouring Temperature 730°C)



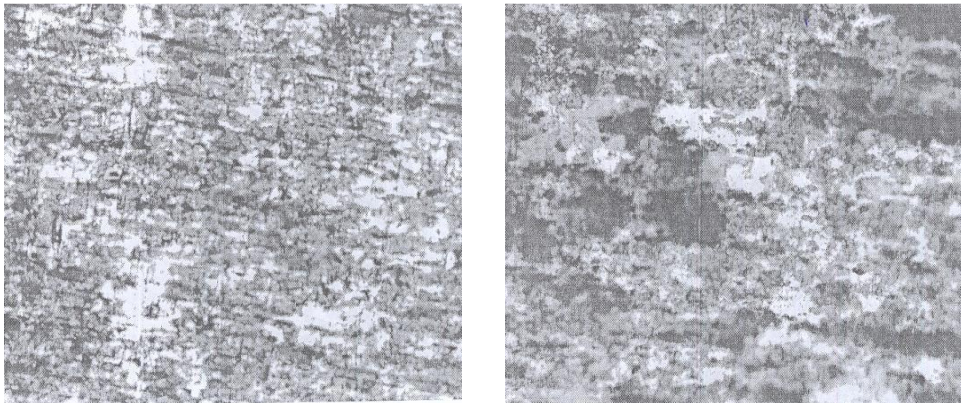
(a) (200 x) (b) (500 x)

Fig.4Optical Micrographs of Alloy A-4 at Different Magnifications (76 ppm P, Pouring Temperature 770°C)



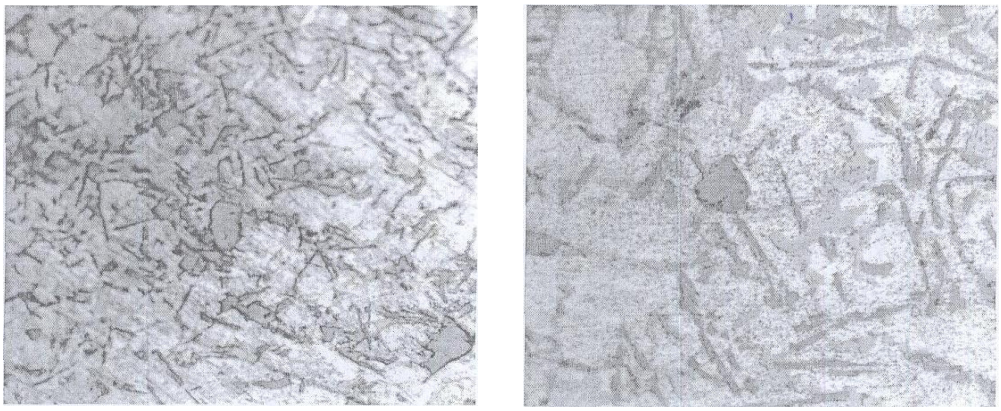
(a) (200 x) (b) (500 x)

Fig.5Optical Micrographs of Alloy A-5 Under Different Magnifications (126 ppm P, Pouring Temperature 770°C)



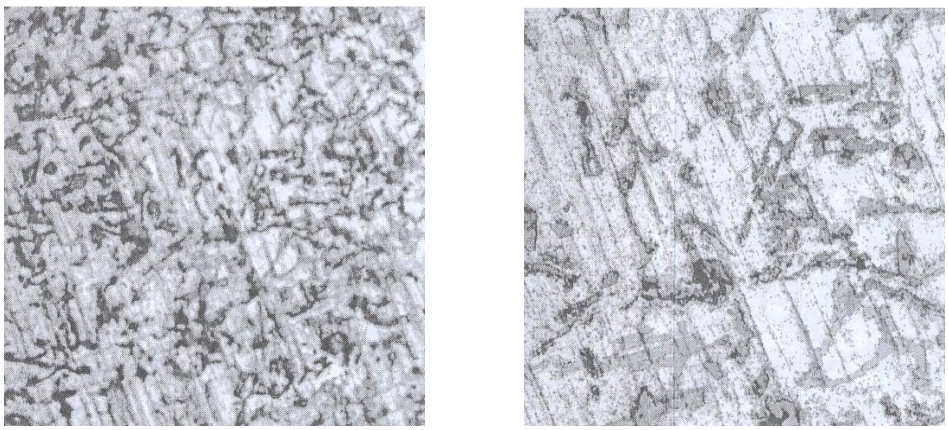
(a) (200 x) **(b) (500 x)**

Fig.6 Optical Micrographs of Alloy B-2 at Different Magnifications (76 ppm P, Pouring Temperature 730°C)



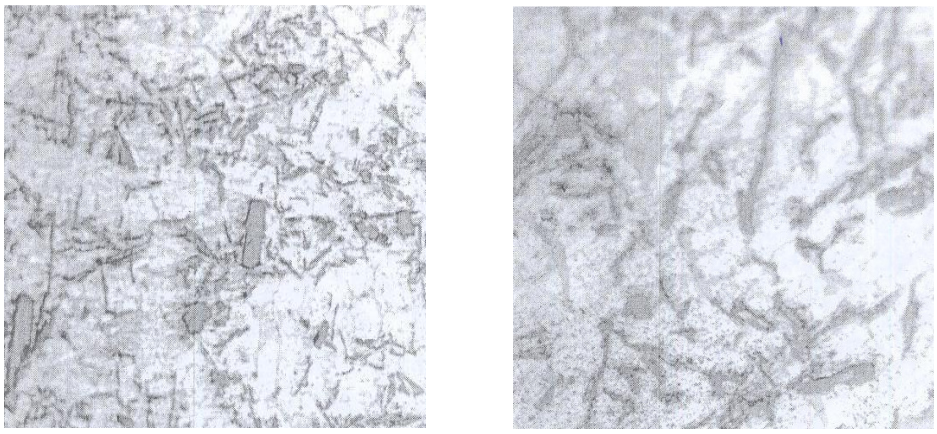
(a) (200 X) **(b) (500 X)**

Fig.7 Optical Micrographs of Alloy B-3 at Different Magnifications (126 ppm P, Pouring Temperature 730¨C)



(a) (200 X) (b) (500 X)

Fig. 8 Optical Micrographs of Alloy B-4 at Different Magnifications (76 ppm P, Pouring Temperature770°C)



(a) (200 X) (b) (500 X)

Fig. 9 Optical Micrographs of Alloy B-5 at Different Magnifications (126 ppm P, Pouring Temperature 770°C)