Investigation on the tensile and hardness properties of primary Si modified Al-20Si alloy

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Abstract - In the present study, Al-20Si alloy has been modified by Cu-13P master alloy to obtain Al-20Si-0.05P and Al-20Si-0.1P alloys. Tensile and hardness tests have been performed on the three alloys and it is found that Al-20Si-0.1P alloy is having better tensile and hardness properties than Al-20Si-0.05P alloy. A Tensile and hardness property of Al-20Si alloy is least among the three alloys. Microstructure of the alloys consisted of primary and eutectic Si distributed in Al matrix. The size of primary Si is much smaller in Al-20Si-0.1P alloy, slightly larger in the case of Al-20Si-0.05P alloy and very coarse in case of Al-20Si alloy. The better tensile and hardness properties of Al-20Si-0.05P and Al-20Si-0.1P alloys are discussed in the light of its modified microstructure evolved during solidification.

Keywords- Al-20Si alloy, Al-20Si-0.05P alloy, Al-20Si-0.1P alloy, Phosphorus, modifier, master alloy, microstructure, tensile and hardness.

I. INTRODUCTION

Al-Si is a simple eutectic system with two solid solution phases, fcc (Al) and diamond cubic (Si). The eutectic temperature of Al-Si is around 577ºC [1]. Considerable interest in replacing cast iron with Al alloys has been considered on the automotive industry to improve energy efficiency and meet environmental requirements. Among them eutectic and hypereutectic Al-Si alloys have been widely used due to their excellent combination of properties such as low thermal expansion and high wear resistance as well as good cast ability [2]. Al-Si alloys are classified based on the silicon composition in the alloy as; hypoeutectic (<11.7%Si), eutectic (11.7-12.6% Si) and hypereutectic (>12.6%Si). Hypereutectic alloys are characterized by a eutectic matrix containing primary silicon crystals of various sizes and shapes. Low thermal expansion coefficient, high strength to weight ratio and excellent wear resistance are amongst the properties of these alloys which account for their popularity as the chosen materials for automotive pistons and engine block [3]. A major metallurgical consideration related to these alloys is to refine the primary silicon phase, which tends to be coarse and non-uniformly distributed. The morphology, size and distribution of silicon particles affect directly the mechanical properties, mach inability and wear resistance of the alloy. The industrial procedure is to treat the alloy with Phosphorus. In hypereutectic Al-Si alloy, CuP master alloy is recognized as the best Si modifier [4-8]. Phosphorus reacts with Al to produce particles of AlP, which in turn acts as nucleation sites for primary silicon [3].

For the present work Al-20Si is prepared and two more alloys with 0.05P and 0.1P are prepared in order to grain modify the alloy. The phosphorus P is added in the form of Cu-13P master alloy. The mechanical properties of all the three alloys Al-20Si, Al-20Si-0.05P and Al-20Si-0.1P are tested and compared.

II. EXPERIMENTAL DETAILS AND RESULTS

The alloys are prepared by chill casting technique. Chill casting process is similar to permanent mold casting. This results in a more uniform part of generally good surface finish and good dimensional accuracy. Mold is made of hardened steel. In this process the molten metal is ladled into the cold chamber. It is particularly useful for metals such as aluminum, copper and its alloys.

Refinement of primary silicon is usually achieved by the addition of phosphorus to the melt. Phosphorus is used to modify the silicon primary particle size when the silicon concentration is greater than 14% [9]. Effective modification is achieved at a very low additional level, but the range of recovered phosphorus of 0.001 to 0.1Wt% is commonly used [10].

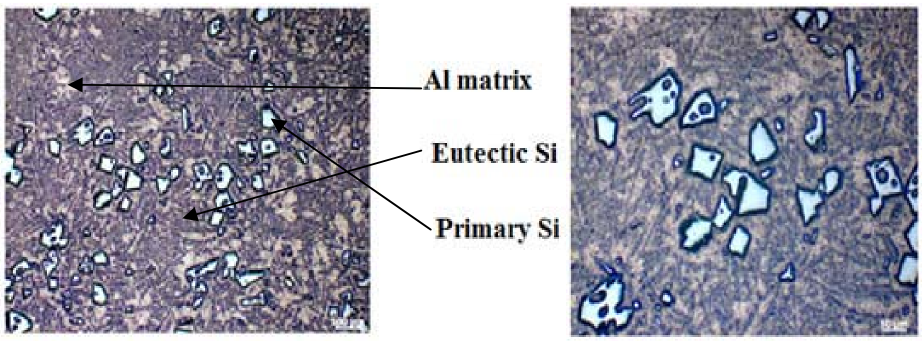
Al-20Si-0.05P alloy is prepared by adding Cu-P master alloy into the molten Al-Si mixture before the molten mixture is poured into the mold. The composition of master alloy used for the present work is Cu-13P. About 7.5g of Cu-13P is added to the molten mixture for producing 1Kg alloy.

Al-20Si-0.1P alloy is also prepared by Cu-13P master alloy. About 14g of Cu-13P master alloy is added to the molten mixture before pouring into the mold.

The alloys prepared are having the following composition;

Elements in %	Al-20Si	Al-20Si-0.05P	Al-20Si-0.1P
Al	79.1	80.5	79.3
Si	20.66	18.95	20.07
P	0.0	0.047	0.12
Fe	0.258	0.331	0.268
Cu	0.0024	0.118	0.325
Mn	0.0013	0.011	0.0008
Mg	0.0033	0.011	0.0045

Fig 1: Composition of alloys.



a b

Fig 2.1: Microstructure of Al-20Si at a) 100X magnification and b) 200X magnification.

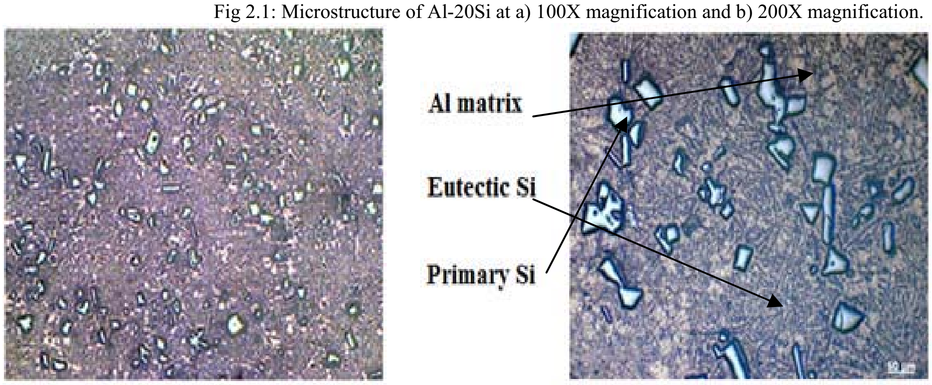


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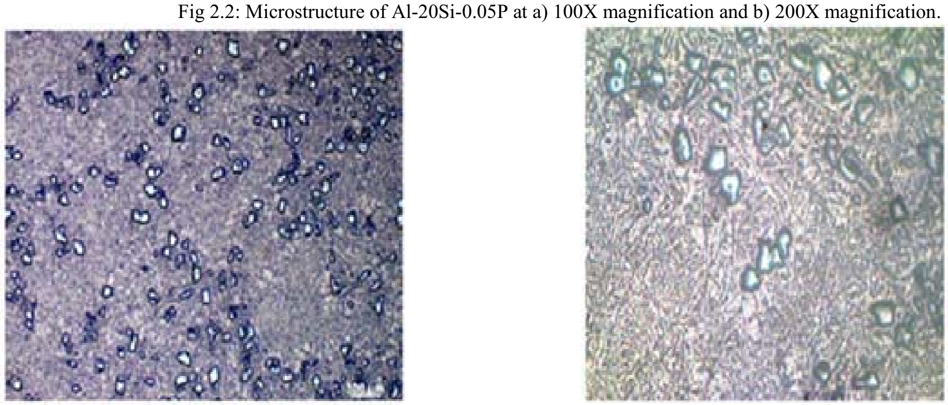
Fig 2.2: Microstructure of Al-20Si-0.05P at a) 100X magnification and b) 200X magnification.



a b

Fig 2.3: Microstructure of Al-20Si-0.1P at a) 100X magnification and b) 200X magnification

It is clearly seen from the microstructures that the primary Si particles range from 50-150μm in Al-20Si alloy, 40-60μm in Al-20Si-0.05P alloy and 10-45μm in Al-20Si-0.1P alloy. This clearly shows the effect of modification. Primary Si particles in Al-20Si-0.05P alloy are modified compared to Al-20Si alloy and those in Al-20Si-0.1P alloys are further modified compared to Al-20Si-0.05P alloy.

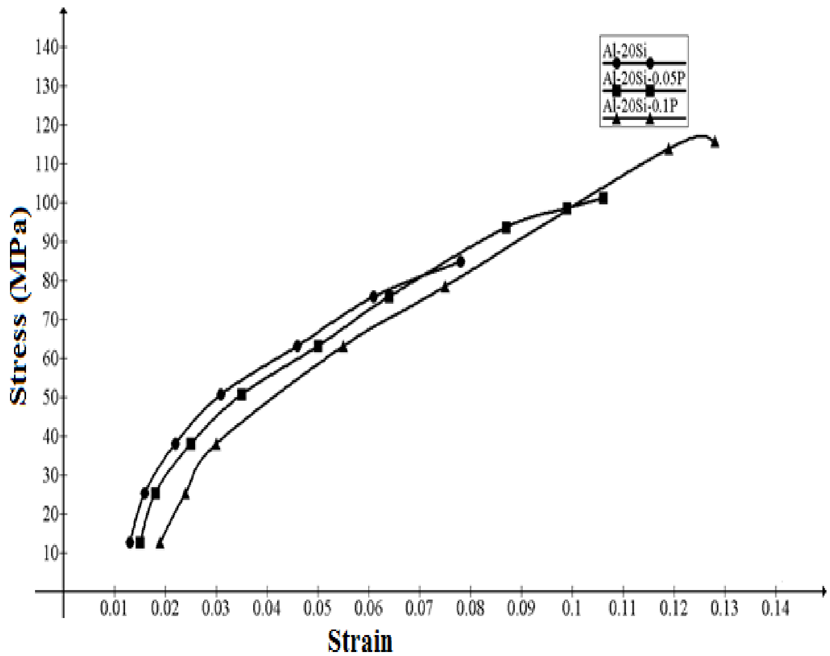


Fig 3: stress versus strain plot

From the above plot it is clearly seen that Al-20Si-0.05P material has an ability to sustain more load than Al-20Si material and Al-20Si-0.1P material has an ability to sustain more load than Al-20Si-0.05P alloy. Also Al-20Si-0.05P material deforms more before failure than Al-20Si material and Al-20Si-0.1P material deforms more than Al-20Si-0.05P material. This clearly shows the effect of grain modification where the grain modified alloys sustain more loads and deform more than the non grain modified alloy.

Material	**Ultimate tensile strength (Mpa)**	**Yield strength (Mpa)**	**Maximum strain**	**% elongation**	% reduction in area
Al-20Si	84.95	46	0.078	7.76	0.8
Al-20Si-0.05P	101.13	55	0.106	10.62	1.41
Al-20Si -0.1P	115.80	67	0.128	12.78	1.81

Fig 4: Tensile test results in tabular form.

Trial No	**Al-20Si**		**Al-20Si-0.05P**		**Al-20Si-0.1P**	
	D (mm)	**VHN**	**D (mm)**	**VHN**	**D (mm)**	**VHN**
1	0.491	76.9	0.461	87.3	0.459	88.0
2	0.511	71.0	0.461	87.3	0.455	89.6
3	0.512	70.7	0.472	83.2	0.451	91.2
4	0.510	71.0	0.462	86.9	0.454	90
Average	**VHN = 72.4**		**VHN = 86.5**		**VHN = 89.4**	

a

Trial No	Al-20Si		Al-20Si-0.05P		Al-20Si-0.1P	
	D	VHN	D	VHN	D	VHN
1	0.369	68.1	0.328	86.2	0.322	89.4
2	0.348	76.6	0.329	85.7	0.316	92.9
3	0.352	74.8	0.335	82.6	0.322	89.4
4	0.369	68.1	0.335	82.6	0.318	91.7
Average	**VHN = 71.9**		**VHN = 84.3**		**VHN = 90.9**	

b

Fig 5: Hardness values obtained by applying a) 10Kg load and b) 5Kg load

At high silicon levels the alloy exhibits excellent surface hardness and wear resistant properties [1]. The large polyhedral shape of primary Si and coarse needle shape of eutectic silicon particles present in the conventionally cast hypereutectic alloy deteriorate their mechanical properties [3]. Silicon particles affect the hardness. Grain refinement of silicon particles lead to an appreciable improvement in hardness.

From the above table it is clearly seen that the hardness value for Al-20Si alloy is less. It increases for Al-20Si-0.05P alloy and it further increases for Al-20Si-0.1P alloy. This clearly shows the effect of grain modification wherein the grain modified alloys are having higher hardness value compared to the non grain refined alloy.

III. CONCLUSION

1. In the present work, Al-20Si alloy has been refined by phosphorus using Cu-13P master alloy to obtain Al-20Si-0.05P and Al-20Si-0.1P alloys.
2. The microstructure of Al-20Si-0.1P alloy is finer than Al-20Si-0.05P alloy and Al-20Si-0.05P alloy is finer than Al-20Si alloy. The primary Si size ranges from 10-45µm in Al-20Si-0.1P alloy, 40-60µm in Al-20Si-0.05P alloy and 50-150µm in Al-20Si alloy. There is about 60% reduction in size of primary Si in Al-20Si-0.05P alloy as compared to Al-20Si alloy. There is a further reduction of around 73% in the size of primary Si in Al-20Si-0.1P alloy as compared to Al-20Si alloy.
3. The observed results of tensile testing are as follows:
   Ultimate tensile strengths for Al-20Si, Al-20Si-0.05P and Al-20Si-0.1P alloys are found to be 85 MPa, 101 MPa and 116 MPa respectively. There is an increase in tensile strength of around 16% in Al-20Si-0.05P alloy compared to Al-20Si alloy. There is a further increase in tensile strength of around 29% in Al-20Si-0.1P alloy as compared to Al-20Si alloy.
4. The observed results of hardness testing are as follows:
   Vickers hardness for Al-20Si alloy is 72. Hardness value increases to 85 for Al-20Si-0.05P alloy and it further increases to 90 for Al-20Si-0.1P. There is an increase of 15% in the hardness value of Al-20Si-0.05P alloy as compared to Al-20Si alloy. There is an increase of 20% in the hardness value of Al-20Si-0.1P alloy as compared to Al-20Si alloy.

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