Effects of Individual Titanium and Combined Additions of Titanium-Boron on Microstructure and Mechanical Properties of Hypereutectic Al-Si Alloys

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Refinement and modification effect of individual additions of Titanium (Ti) and combined additions of titanium-boron (TiB) are studied on hypereutectic Al-13, 14, 15, 17 and 20 Si alloys using image analyser and Scanning Electron Microscope (SEM). It can be clearly seen from the results that combined additions of Ti and B in the form of Al-5Ti-1B has a good refining effect on primary silicon, in comparison with individual elemental addition of titanium (Ti) in the form of Al-5Ti. However, there is no significant eutectic modification with either individual or combined addition of titanium and boron (B). In addition, Ti in conjunction with B proves to be better in achieving improved mechanical properties such as hardness and ultimate tensile strength (UTS) rather than individual Ti.

Keywords: Refinement; Hypereutectic Al-Si Alloys; SEM.

Introduction

Hypereutectic Al-Si alloys find their applications in aerospace and automotive industries due to their excellent casting characteristics, wear resistance and strength-to - weight ratio. But the presence of hard, large, irregular shaped brittle primary silicon and eutectic silicon leads to premature crack ignition in tension. Hence it is advised to have refined primary silicon with modified eutectic silicon. However, many methods are in practice other than that of elemental additions[1-18]. But these processes are complex and difficult to control[19]. Hence elemental addition method is widely practised in foundries to achieve effective refinement and modification of primary and eutectic silicon[19]. Many researchers dedicated their work on refinement of primary silicon in hypereutectic Al-Si alloys by elemental additions[20-32], it is a known fact that considerable improvement in mechanical properties cannot be achieved without the modification of eutectic silicon[33]. Strontium proves to be a better modifier of eutectic silicon but it has a tendency to deactivate the phosphorous effect[34]. Effect of boron on hypoeutectic Al-Si is studied by Geng et al.[35] who reported that it has little or no effect on eutectic silicon. In spite of voluminous work on refinement of hypereutectic Al-Si alloys, no consensus exists on the effect of Boron[36]. Hence, in the present study, efforts have been made to study the individual (Ti) and combined (TiB) effects on microstructure and mechanical properties of Hypereutectic Al-Si alloys.

Materials & Methods

Preparation of the Alloys

Hypereutectic Al-Si alloys are prepared via foundry technique. Calculated quantities of CPAL (99.7wt% purity) and A1-20 wt% Si master alloy are melted in a resistance furnace under cover of flux. Hexachloroethane is added to the melt, which acts as a degasifier. After the degasification, Al-5Ti-1B chips are added to the melt and the melt is stirred for 30 seconds. The melt is held in the furnace for about 5 minutes and later it is poured into graphite mould. The same procedure is repeated with the addition of Al-5Ti for all the alloys taken for study i.e., Al-13, 14, 15, 17 and 20 Si alloys. A constant addition level of 0.15% TiB/Ti is maintained for all the alloys taken for study. The cast specimens are taken for evaluation of mechanical properties and characterisation using image analysis and SEM studies.

Microstructural Studies

From optical and SEM photographs shown in Figs. 1 and 2 it is clear that, as-cast Al-13,14,17,20 Si alloys contain primary silicon and eutectic silicon in coarse irregular and long needle like morphologies. These morphologies

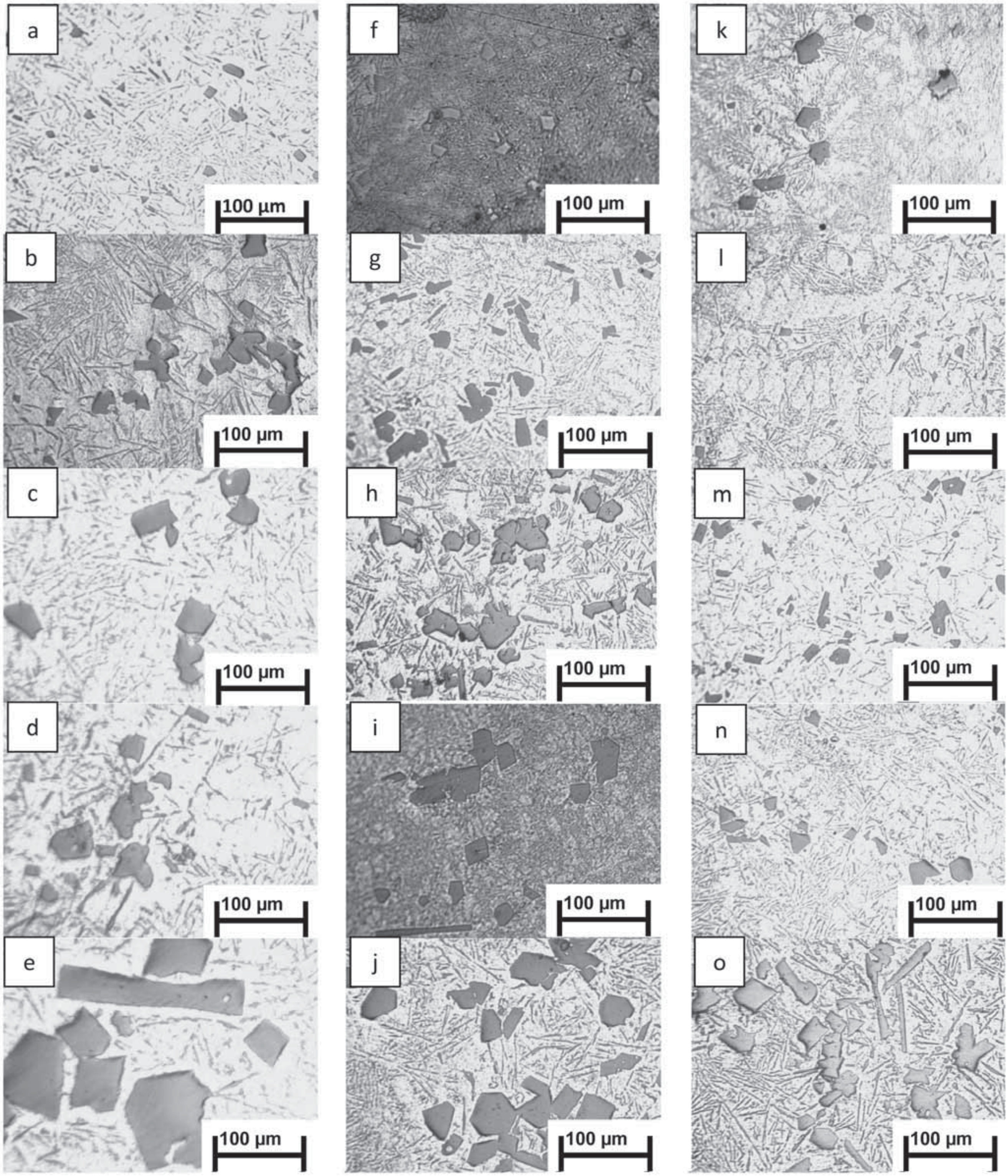

Fig. 1: Optical photo micrographs (200X) of as-cast, TiB and Ti-treated hypereutectic Al-Si alloys.

(a), (b), (c), (d), (e) As-cast hypereutectic Al-13, 14, 15, 17 and 20 Si alloys. (f),(g),(h),(i),(j) Al-13,14,15,17 and 20 Si alloys treated with 0.15% TiB. (k), (l), (m), (n), (o) Al-13, 14, 15, 17 and 20 Si alloys treated with 0.15% Ti.

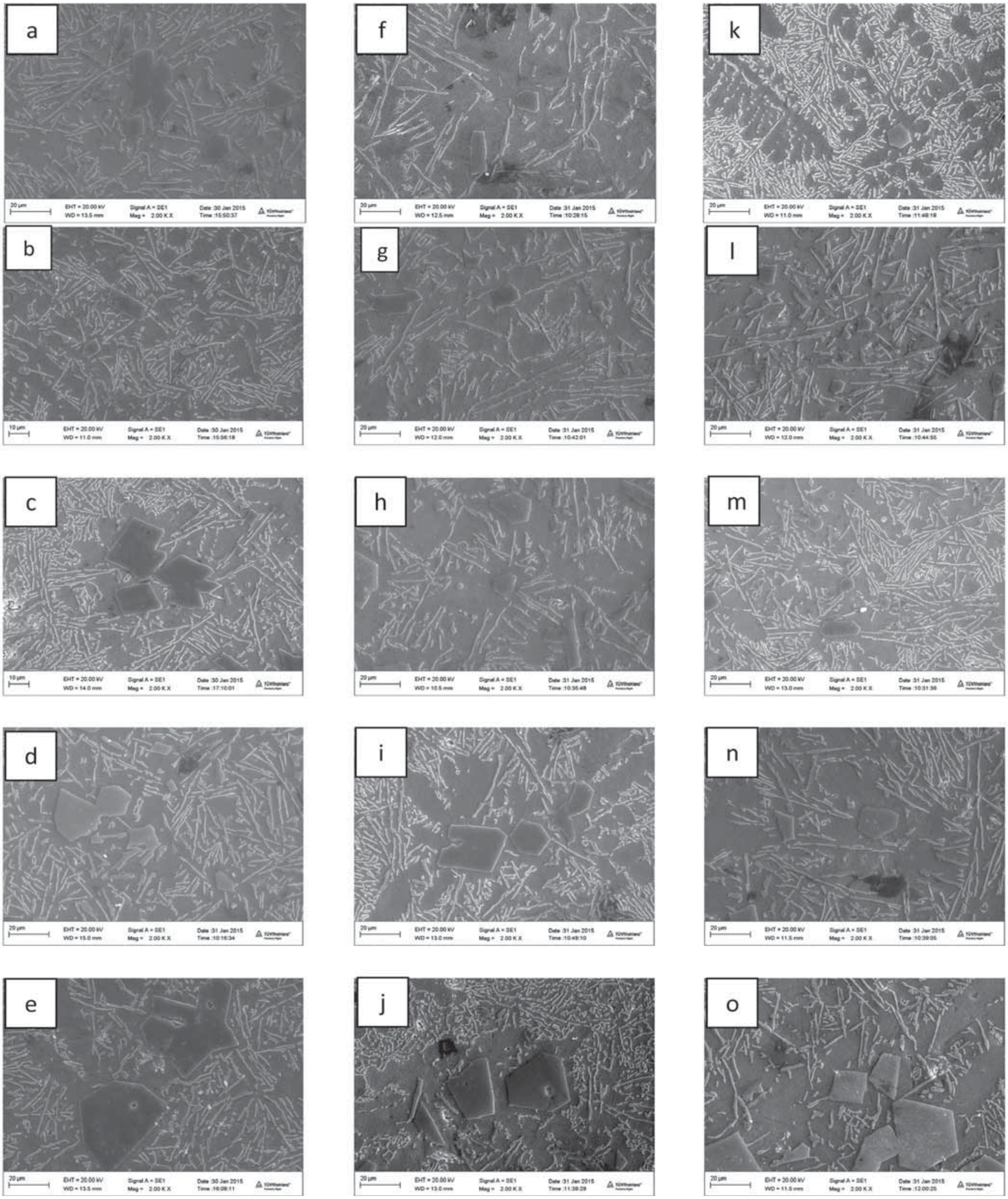

Fig. 2 : SEM photographs of as-cast, TiB and Ti-treated hypereutectic Al-Si alloy.
(a),(b),(c),(d),(e) As-cast hypereutectic Al-13,14,15,17 and 20 Si alloys (f),(g),(h),(i),(j) Al-13,14,15,17 and 20 Si alloys treated with 0.15% TiB (k),(l),(m),(n),(o) Al-13,14,15,17 and 20 Si alloys treated with 0.15% Ti

have detrimental influence on the mechanical properties. Fracture in tension due to premature crack initiation is attributed to the brittleness of large size primary and eutectic silicon. Whereas with the addition of 0.15 % TiB and Ti in the form of Al-5Ti-1B and Al-5Ti reduction in size of primary silicon particles is seen with modification in the form of shortening in growth of eutectic silicon the results upholds the conclusions made by Cibula[37]. Table-1 clearly depicts the decrease in average size of primary silicon particles with the addition of TiB and Ti to as-cast Al-13, 14, 17, 20 Si alloys. Figure 3 also clearly shows the effect of TiB and Ti addition on the modification and shortening of growth of eutectic silicon in as-cast Al-13, 14, 17, 20 Si alloys. From Figs.1 and 2 and Table-1, it is clear that Ti in conjunction with B proves to be a better refinement element rather than individual, the present study supports the earlier studies of Cibula A. (1949-1950) that have given a remark that TiB has a better grain refining effect than either Ti or B individually.

Table 1: Average Size of Primary Silicon after the Addition of TiB or Ti

Alloy Composition	Primary Silicon Particle Size in µm
Al-13Si	15.45
Al-13Si+0.15% Al-5Ti-1B	9.15
Al-13Si+0.15% Al-5Ti	10.25
Al-14Si	16.93
Al-14Si+0.15% Al-5Ti-1B	12.25
Al-14Si+0.15% Al-5Ti	13.35
Al-15Si	24.39
Al-15Si+0.15% Al-5Ti-1B	18.52
Al-15Si+0.15% Al-5Ti	19.95
Al-17Si	25.09
Al-17Si+0.15% Al-5Ti-1B	20.50
Al-17Si+0.15% Al-5Ti	20.95
Al-20Si	45.03
Al-20Si+0.15% Al-5Ti-1B	21.35
Al-20Si+0.15% Al-5Ti	22.45

Hardness Studies

Figure 4 shows the influence of TiB and Ti additions on hardness (VHN) of Al-13, 14, 15, 17 and 20 Si alloys. Figure 4 reveals the improvement in hardness of as-cast alloys achieved with the addition of TiB and Ti. The improvement in the hardness is due to the microstructural changes. In the present study, homogeneous dispersion of fine hard particles is achieved by addition of 0.15% of TiB and Ti to hypereutectic Al-13, 14, 15, 17 and 20 Si alloys during solidification. The results of the Vickers hardness test (VHN) revealed that hardness of the matrix of hypereutectic Al-Si alloys increases with an increase in weight percentage of silicon in Al-Si alloys. This could be due to the presence of large-size polyhedral silicon particles in hypereutectic Al-Si alloys. However, further improvement in hardness of the same alloy is observed with the addition of 0.15% TiB and Ti to the melt. Addition of TiB and Ti leads to refinement of primary silicon particles due to heterogeneous nucleation. Further, refined alloys exhibit higher VHN due to even distribution of smaller sized primary silicon particles throughout the matrix when compared to as-cast alloys. Experimental results show that as-cast hypereutectic Al-13, 14, 15, 17 and 20 Si alloys show VHN of 56.6, 59.95, 63.04, 65.09, and 74.90 respectively. While with the addition of TiB and Ti to the melt, the same alloys shows improvement in VHN and are clearly observed from Fig. 4. Ti in conjunction with B proves to be better refinement element in achieving improved hardness as compared to individual.

Tensile Studies

Figure 5 (a) and (b) shows the influence of TiB and Ti addition on mechanical properties of Al-13, 14, 15, 17 and 20Si alloys. It is clear from the figures that, UTS and ductility decreases with increase in Si content beyond 13% for all the compositions studied and both with and without Ti and or B additions. The decrease in ultimate tensile strength and ductility in the hypereutectic Al-Si alloys could be due to increase in silicon content. The presence of coarse primary silicon phase in these alloys induces brittleness and hence the corresponding plastic deformation of the matrix decreases. However, addition of 0.15 % TiB or Ti to the melt for the same alloys resulted in improvement in mechanical properties when compared to the base alloys. The improvements obtained could be attributed to decrease in the size of the primary silicon particles after the refinement due to the addition of TiB or Ti when compared to the as-cast alloys. However, higher ultimate tensile strength and increased percentage elongation is observed incase of alloys which are treated with combined addition of TiB when compared to individual Ti addition and as-cast alloys. The improvements obtained with combined addition of TiB could be due to better refining than individual addition of Ti. i.e. with combined addition of TiB, both TiB_2 and Al_3Ti particles are effective in refinement when compared to Al_3Ti alone.

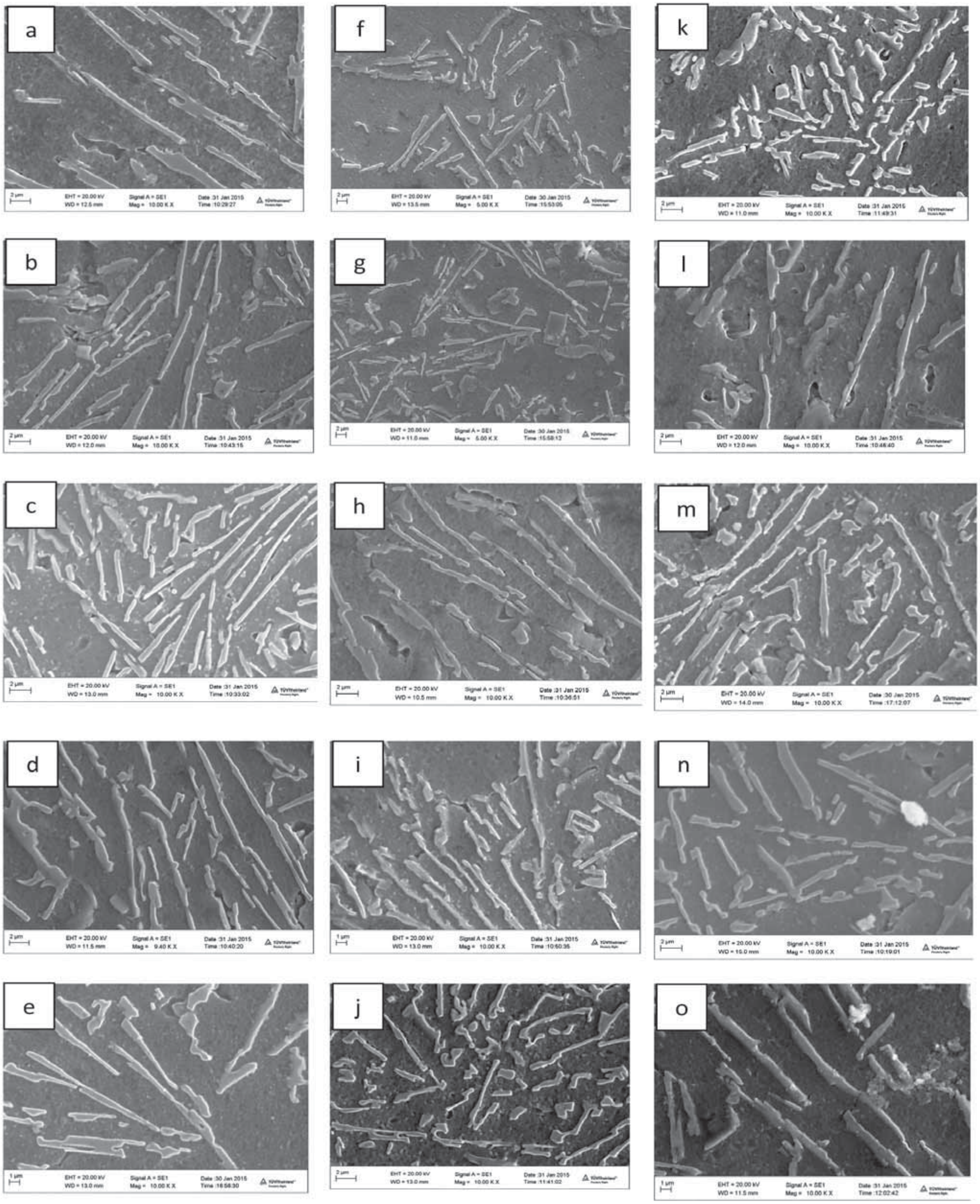

Fig.3: SEM photographs of as-cast, TiB and Ti-treated hypereutectic Al-Si alloys showing the size and shape of eutectic silicon. (a),(b),(c),(d),(e) As-cast hypereutectic Al-13,14,15,17 and 20 Si alloys (f),(g),(h),(i),(j) Al-13,14,15,17 and 20 Si alloys treated with 0.15% TiB (k),(l),(m),(n),(o) Al-13,14,15,17 and 20 Si alloys treated with 0.15% Ti

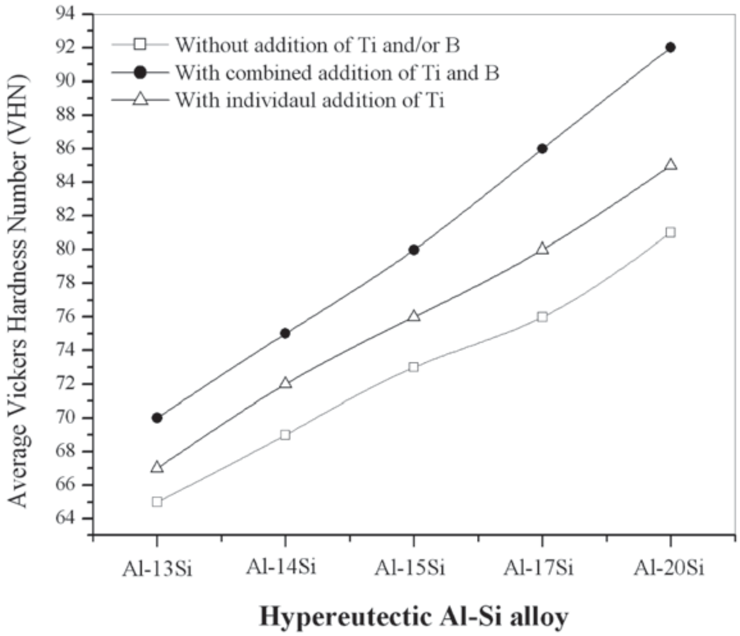

Fig. 4: Effect of TiB and Ti addition on Average Vickers hardness number of hypereutectic Al-Si alloys.

Conclusions

The effect of addition of TiB and Ti on as-cast hypereutectic Al-Si alloys is more distinct. Refinement of primary silicon is seen with the addition of Al-5Ti-1B and Al-5Ti along with modification in the form of stunting in growth of eutectic silicon. Mechanical properties of hypereutectic Al-Si alloys improves with the addition of TiB and Ti. However, Ti in conjunction with B proves to be a better refining element rather than individual addition.

Some of the specific conclusions that can be drawn for each of the alloys taken for study and are listed below:

1) In Al-13, 14, 15, 17 and 20Si alloys addition of 0.15% Ti, has resulted in hardness of 67, 72, 76, 80 and 84 VHN. However, addition of 0.15%TiB has increased hardness to 70, 75, 80, 82 and 90 VHN.

2) Combined addition of 0.15%TiB to Al-13, 14, 15, 17 and 20Si alloys has resulted in higher UTS values of 199.82, 195.60, 190.50, 189.20 and 180.32 MPa, when compared to the individual addition of 0.15%Ti and as-cast alloys. Also, addition of 0.15%TiB to Al-13, 14, 15, 17 and 20Si alloys has resulted in improvement in ductility in these alloys in comparison with 0.15%Ti and as-cast alloys.

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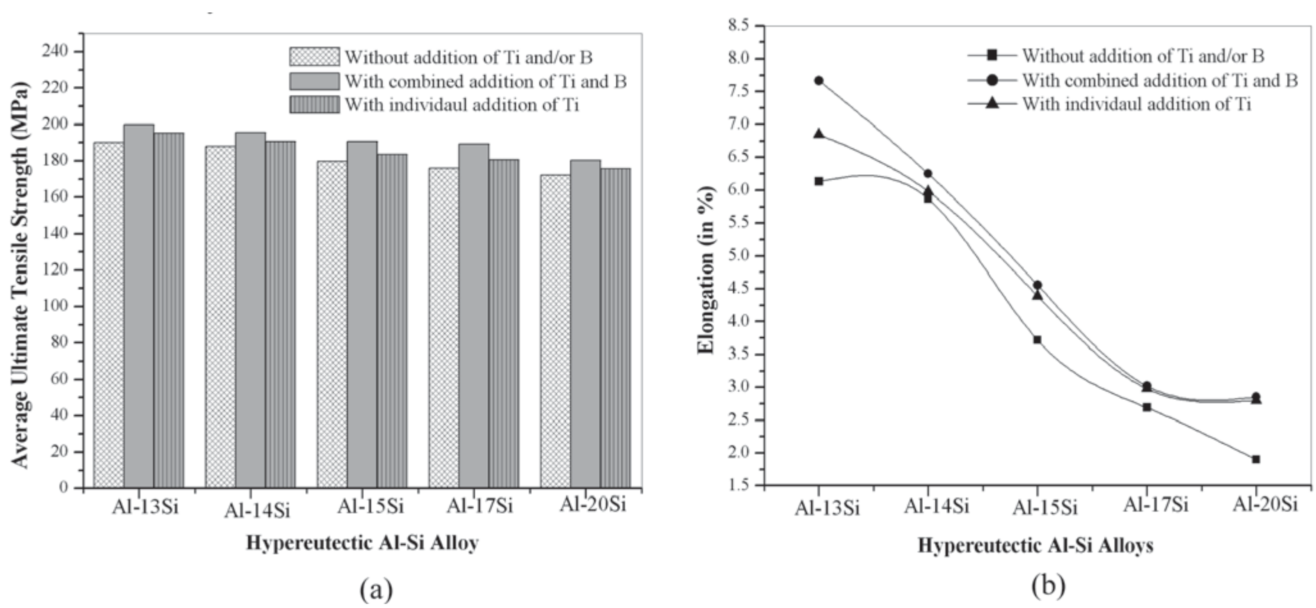

Fig. 5 (a-b): Effect of combined (TiB) and individual (Ti) addition on average ultimate tensile strength and percentage elongation of hypereutectic Al-Si alloys.

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