Experimental Study on Mechanical Properties of LM6 Metal Matrix Composite with Ti-Boron Reinforcement

Santosh V. Janamatti[1*], Ganesh Rao I.N.[2], Rakesh H.[3] Manasa T.[4] Arul Mary A .[5]

[1] Assistant Professor, Dept. Of Mechanical Engineering, Ballari Institute of Technology and Management, Ballari, Karnataka, India

[2] U.G Students, Dept. Of Mechanical Engineering, Ballari Institute of Technology and Management, Ballari, Karnataka, India

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Abstract – *LM6 metal matrix composite have been increasingly used in advanced applications like Aerospace, Automobiles and Marine. These composites are subjected to different environmental conditions, hence this work deals with producing Aluminium based metal matrix composite and then studying its mechanical properties such as Tensile strength, Impact strength, Shear strength, Torsional strength and Hardness with produced test specimen. In this present study a modest attempt has been made to develop all properties with low cost method of casting technique. Aluminium alloy and titanium-boron has been chosen as a matrix and reinforcing material respectively, experiment has been conducted by varying weight fraction of 18% & 20% of titanium-boron. The mechanical properties may vary with the increasing percentage of reinforcement. Test specimens have been prepared using Stirrer casting technique. Sizes of the specimens are according to ASTM standards. Test specimens were subjected to different testing conditions and properties have been enhanced.*

Key Words**:** LM6 aluminium alloy, Ti-Boron, Stir casting, Metal matrix composite, Mechanical properties.

1. INTRODUCTION

Metal matrix composites (MMCs) are being increasingly used in aerospace and automobile industries owing to their enhanced properties such as Tensile strength, Impact strength, Shear strength, Torsion strength and Hardness. The commonly used metallic matrices include Aluminium, magnesium, titanium and their alloys. These alloys are commonly preferred matrix materials for the production of MMCs.

The metal matrix Aluminium LM6 alloy is preferred, as Aluminium is a eutectic alloy which has a major composition of 85% - 95% of Aluminium and 11%-13% of silicon and its ability to resists hot cracking, pressure tightness, die filling capacity and corrosion resistance makes it has a commonly used alloy for automotive as well as aeronautical applications.

. The test samples were fabricated by the stirrer casting method and the addition of titanium-boron Aluminium grain refines improves homogeneity & allows for a uniform distribution of alloying elements, reduces porosity, eliminates hot tearing in cast structures, improves responsiveness to subsequent heat treatment & enhances mechanical properties & machinability in fabrication process. Aluminium alloy & titanium boron has been chosen as a matrix & reinforcing material respectively, experiment has been conducted by varying weight fraction of 18% & 20% of titanium boron.

1.1 LM6 Aluminium Casting Alloy (Al – Sil2)

LM6 alloy is essentially a hypoeutectic Al-Si alloy (typically consists of 11.5wt% Si, less than 12.6wt% Si of eutectic composition) with low copper content (<0.1 wt %) to impart it the excellent property of corrosion resistance under both ordinary atmospheric and marine conditions. The LM6 alloy possesses exceptional fluidity so that it is capable of producing intricate castings of thin sections. It is also resistant to hot tearing when cast in sand or chilled moulds throughout a wide range of temperatures. LM6 is especially suited to castings that need to be welded although special care is needed when machining. Carbide-tipped tools with large rake angles and relatively low cutting speeds give comparatively good machining results provided cutting lubricant and coolant are employed in the machining process. Some of the applications of LM6 alloy are marine on-deck castings, water-cooled and inlet manifolds, motor housings, doors, chemical equipment, dye and food equipment, and tools.
The inferior mechanical properties of this type of structure make modification of Al-Si based casting alloys necessary. Modification is meant to change the shape of the silicon phase from flake to fibrous. Changing the morphology of eutectic Si from its original coarse acicular structure to a finer fibrous structure will enhance the mechanical properties of Al-Si castings significantly. In general, modification can be achieved by rapid solidification (quench solidification) or impurity modification (chemical modification). The ubiquitous modifier used in foundry industry is Al-Si master alloy that contains ~10wt% of strontium. Besides modification, grain refinement of Al-Si alloys is also a major treatment encountered in foundries. Grain refinement plays a vital role in cast and wrought aluminium alloys in terms of eliminating the associated defects caused by coarse columnar grain structure. Such defects are exemplified in reduced fabric ability, yield strength and tensile elongation to fracture; hot cracking is severe in the shell zone of a continuously cast ingot as well. Achieve the desired quality of LM6 sand casting through

proper mould design, determination of appropriate casting modulus and process parameters.

2. RELATED WORK

[1] has studied on the metal matrix composites of an aluminium –silicon based alloy (LM6) with lead oxide glass particles with % addition of 2.5%,5%,7.5%, and 10% were produced using sand casting technique. Variation in composition, mechanical properties and microstructure properties were examined .The change in volume of silicon and lead content was examined in the spectroscopic analysis. They found that tensile strength and hardness increased with increase in % reinforcement. [2] Investigated on the mechanism of heterogeneous grain refining of aluminium by ultrafine element boron particles. To observe the boron-Aluminium interface boron filament was introduced in a melt at 1013K containing different levels of Ti. From the experimental results they found that boron is dissolve in pure Aluminium while its dissolution is inhibited in presence of titanium solute.[3] has studied on effects of processing parameters on the performance of Al grain refinement master alloys Al–Ti and Al–B in small ingots. Author found that most of the works on grain refining performance of Al–Ti and Al–Ti–B master alloys have been devoted to the influence of their chemical composition, parent–metal composition and processing parameters such as holding temperature, contact time, mechanical agitation and cooling rate on a grain refiner effectiveness. [4] has studied on Aluminium –Titanium Diboride metal matrix composites This paper presents an overview of Al-TiB2 MMC on aspects relating to the formation of Tib2, development of Al-TiB2 ,mechanical characteristics, thermodynamic calculation ,wear behaviour of Al-TiB2 , cycle fatigue response of insitu Al based composite, processing ,microstructure, properties and applications. [5] has worked with fabricating or producing aluminium based metal matrix composite and then studying its microstructure and mechanical properties such as tensile strength, impact strength and wear behaviour of produced test specimen. In this study a modest attempt has been made to develop aluminium based MMCs with reinforcing material with an objective to develop a conventional low cast method of producing MMCs and to obtain homogeneous dispersion of reinforced material. To achieve this objective stir casting technique has been adopted. The result has shown that the increase in addition of Fly Ash is giving better result when compared with Redmud. [6] Investigated three types of Al–5Ti master alloys were synthesized by a method of thermal explosion reaction in pure molten Aluminium. Performance comparison of Al–5Ti master alloy in grain refinement of commercial purity Al with different additions (0.6%, 1.0%, 1.6%, 2.0%, and 3.0%) and holding time (10, 30, 60 and 120 min). The results show that Al–5Ti master alloy with blocky TiAl3 particles clearly has better refining efficiency than the master alloy with mixed TiAl3 particles and the master alloy with needle-like TiAl3 particles.

The above review for the aluminium based metal matrix composite leads to the following conclusions: Among the different fabrication procedure, Stir casting method is an effective casting method to develop the metal matrix composites, to obtain uniform distribution of the reinforcement and homogeneous properties of the casting. It is also widely acceptable method due to its low cost and easy portability. The addition of alumina, SiC, B4C, fly ash, TiC etc. particles in aluminium improves the hardness, yield strength, tensile strength and ductility. Aluminium and its alloys reinforced with ceramics articles have shown an improvement in mechanical properties and tribological properties.

Based on authors investigation, it has been found that the research on the following aspects of the Aluminium-titanium -boron MMCs is relatively limited and may attract more interests in the future research.

It has been shown that addition of titanium boron particles to Aluminium alloys has a direct effect on some important features such as microstructure, thermal properties & mechanical properties. Content higher than those traditionally used for grain refining purposes that is around 0.2 volume % that may compensate the higher cost of material. Hence further more properties may be tailored & adjusted to the specific requirements of the industry based on titanium boron content within the alloy that might be useful for the following purposes:

1) To study the improved mechanical properties such as tensile strength, impact strength, shear strength & tensional strength.

2) To study the behavior of reinforced materials with other processes.

3. METHODOLOGY

In this study we have considered LM6 aluminium alloy as matrix and titanium boron as reinforcement, the variation of titanium boron is 18% and 20% in LM6 matrix. The method used for casting the metal matrix composites is Stir casting technique. From now on in this paper LM6-20% Ti-B represents 20% Titanium Boron in LM6 alloy and LM6-18% Ti-B represents 18% Titanium Boron in LM6 alloy

3.1STIRRER CASTING

Stir casting technique is simple and the most commercial method of production of metal matrix composites. In preparing metal matrix composites by the stir casting method, there are several factors that need to be considered, including:
1. Difficulty in uniform distribution of the reinforcement material.
2. Wettability between the two main substances.
3. Porosity in the cast metal matrix composites, and
4. Chemical reactions between the reinforcement material and the matrix alloy.
In conventional stir casting method, reinforced particulate is mixed into the aluminium melt by mechanical stirring.

Mechanical stirring is the most important element of this process. After the mechanical mixing, the molten metal is directly transferred to a shaped mould prior to complete solidification. The essential thing is to create the good wetting between particulate reinforcement and aluminium melt. The distribution of the reinforcement in the final solid depends on the wetting condition of the reinforcement with the melt, relative density; rate of solidification etc .Distribution of reinforcement depends on the geometry of the stirrer, melt temperature and the position of the stirrer in the melt. Fig 1 shows a schematic diagram of stir casting process.

An improvement in conventional stir casting is a double stir casting method or two-step casting process. In the first stage, the matrix material is heated to above its liquidus temperature and then cooled down to a temperature to keep in a semi-solid state. At this stage, the preheated reinforcement materials are added and mixed with a mechanical stirrer. Again the slurry is heated to a liquidus state and mixed thoroughly. Nowadays, this two-step mixing process has used in the fabrication of aluminium because of more uniform microstructure as compared of conventional stirring. A recent development in stir casting is three step stir casting for the fabrication of nanoparticles reinforced composite. In this method, first, the Al particles and reinforcement are mixed using ball milling process to break down the initial clustering of nanoparticles. Then the composite powder is mixed with melt by mechanical stirring .The present study deals with the stir cast aluminium matrix composite regarding their enhanced properties such as mechanical, tribological, and thermal.

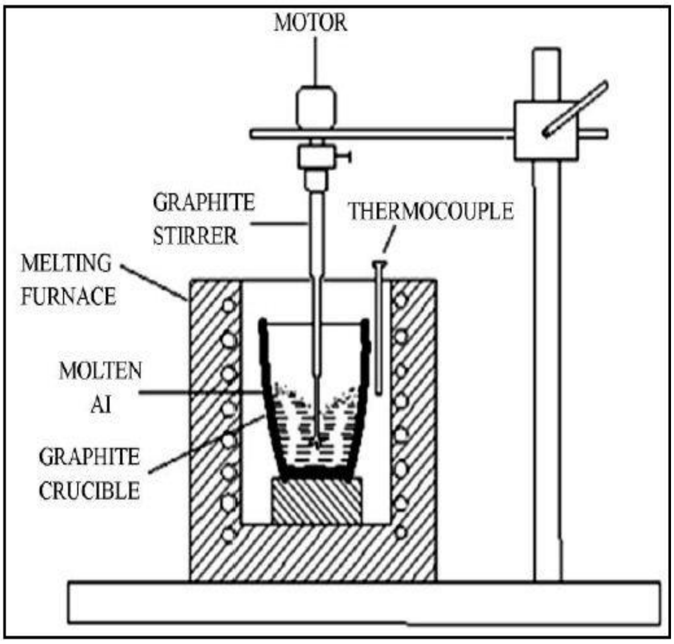

Fig: 1 Stir casting technique

4. RESULTS AND DISCUSSION:

Following are the tests carried out to check the mechanical properties of LM6 –Titanium boron (LM6-Ti-B) metal matrix composites.

4.1 TENSILE TEST

Tensile strength is a measurement of the force required to pull something to the point before it breaks .Tensile test was done using Universal Testing Machine (UTM) fig 2. The Specimen used as per ASTM E8 standard. The specimen made of LM6 –Titanium boron (LM6-Ti-B) metal matrix composites having 20% titanium boron (LM6-20% Ti-B) is used for tensile test . Fig 3 (a) and (b) shows the specimens before and after tensile testing.

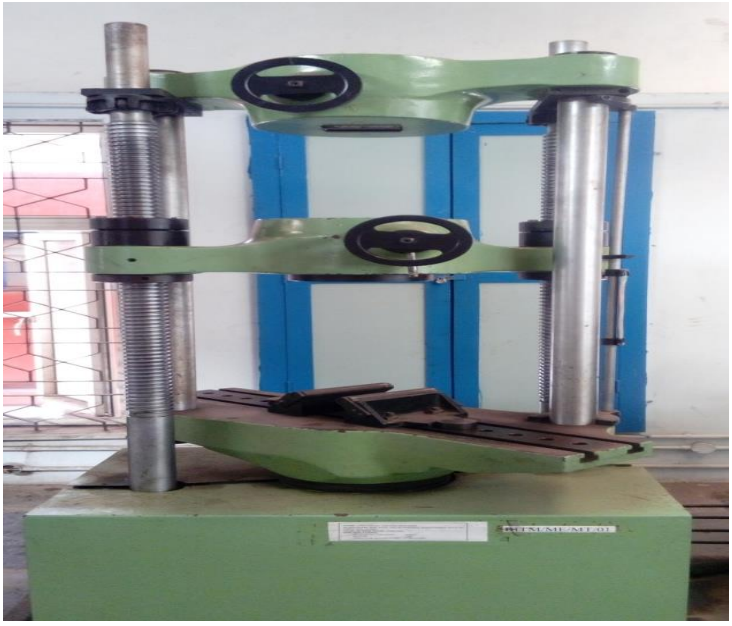

Fig:2 Universal Testing Machine

(a)

b)

Fig: 3 Tensile test specimens: before testing and after testing

Table1: Tensile test results of 20% Ti-B inLM6-Ti-B mixed composites

Specimen	LM6-20% -Ti-B
Yield Stress (Mpa)	78.5
Tensile Strength (Mpa)	157
Percentage of Elongation	10.625%

From the tensile test conducted for the LM6-20%-Ti –B, the yield stress, tensile strength and the percentage elongation results are as tabulated in Table 1

4.2 HARDNESS TEST

Hardness is the resistance of a material to localized deformation. A hard material surface resists indentation or scratching and has the ability to indent or cut other materials. Hardness of the four stir casted samples was tested on Brinell hardness tester Figure 4 and Vickers hardness tester Figure 5. The ball is then removed and the diameter of the resulting indentation is measured using a Microscope .The Specimen used is per IS 1500 standard. Readings on 3 locations were taken and average reading of each sample was considered. Two specimens one consisting of 18% Ti-B and the other consisting of 20% Ti-B is used to check the hardness. Fig:6 Shows the specimens after conducting the hardness test.

Fig: 4 Brinell Hardness Testing Machine

Fig: 5 Vicker's Hardness Testing Machine

Fig: 6 Hardness specimens of LM6-18% -Ti-B and LM6-20% -Ti-B

TABLE 2: Brinell and Vickers Hardness Number

HARDNESS	*LM6-18% -Ti-B*	*LM6-20% -Ti-B*
BHN NUMBER	*73*	*88*
VHN NUMBER	*64*	*76*

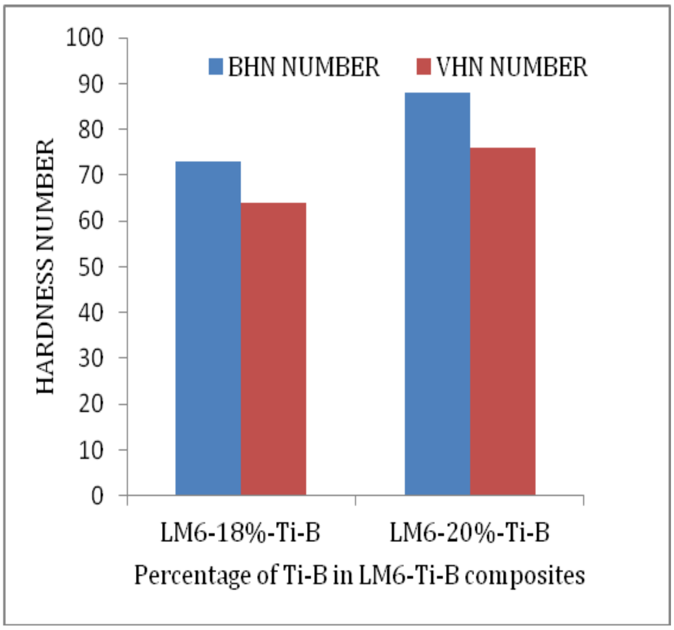

Fig 7: Hardness number

From the Table 2 and the fig 7 we can observe that hardness is going to increase with the increase in percentage of Ti-B in the composite.

4.3 IMPACT TEST

In an impact test a notched bar of material, arranged either as a cantilever or as a simply supported beam, is broken by a single blow in such a way that the total energy required to fracture it may be determined. The energy required to fracture a material is of importance in cases of -shock loading when a component or structure may be required to absorb the K.E of a moving object. Energy absorbed is the energy which is absorbed by the material. The energy is calculated in joules. The energy absorbed is calculated the energy available at the end. The energy absorbed can be found with the help of Charpy impact tests and Izod impact tests. The standard specimen size for impact testing is 10mm×10mm×55mm. The standard specimen is machined from the bars with notches and is used for Izod and Charpy test, a V-notch and a Square prism notched specimen is used. Fig 8 shows the Impact testing machine. The specimen is placed as a simple beam being towards and opposite side of the pendulum knife edge. For Izod test and charpy test, prismatic or cylindrical specimen notched is clamped to act as a cantilever with the notch on the side the load is applied. Fig 9 and 10 shows the Charpy and Izod Specimen before Testing and after Testing.

Fig: 8 Impact testing machine

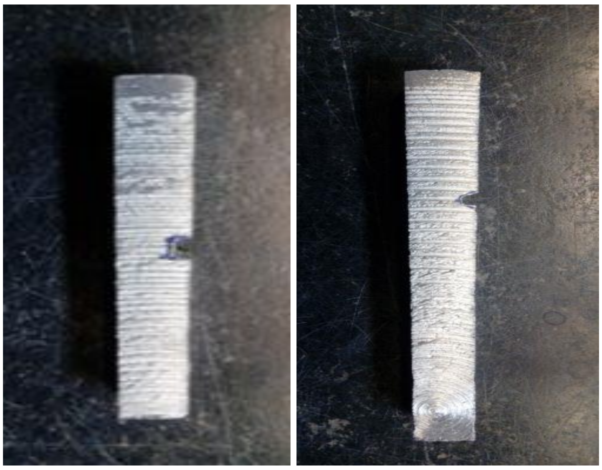

Fig: 9 Charpy And Izod Specimen before Testing

Fig: 10 Charpy and Izod Specimen after Testing

TABLE 3: Impact strength values

TEST	IZOD TEST	CHARPY TEST
SPECIMEN	LM6-20% -Ti-B	LM6-20% -Ti-B
IMPACT STRENGTH (JOULES/ MM^2)	0.0125	0.025

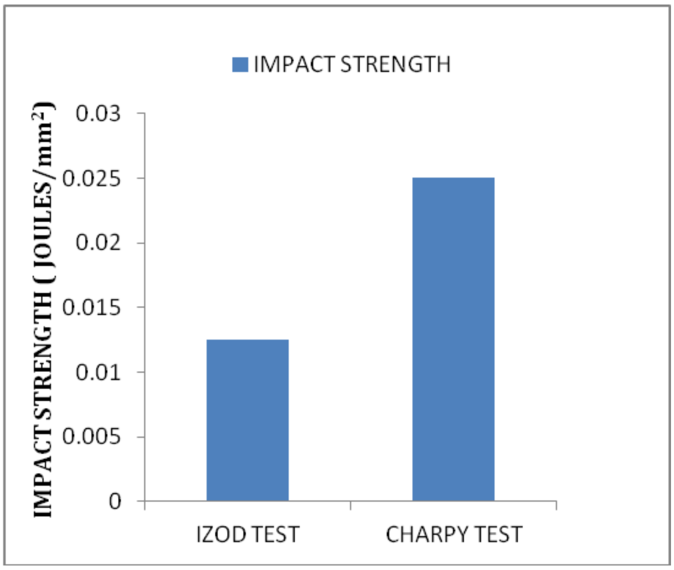

Fig:11 shows the impact strength values of Izod and charpy test for LM6-20% -Ti-B specimen

4.4 SHEAR TEST

The shearing stress acts parallel to a plane where as tensile and compressive stress acts normal to a plane. Torsional tests are employed to evaluate the basic shear properties of a material. Fig 12 and 13 shows the specimen subjected to double shear.

The diameter of the specimen is measured using a micrometer. Specimen is fixed in the shackles for either single shear or double shear. Loading is done slowly at right angles to the axis of the specimen through the central block. Load at fracture is noted down. Shape and texture of the fractured surface is studied.

Ultimate strength = F/2A, for double shear

Fig: 12 Specimen before testing [Ø16mm] and after testing

Fig: 13 Specimen before testing [Ø20mm] and after testing

TABLE 4: Shear Stress Values for LM6-18% -Ti-B

DIAMETER in mm	SHEAR STRESS (N/mm^2)
16	133
20	**129**

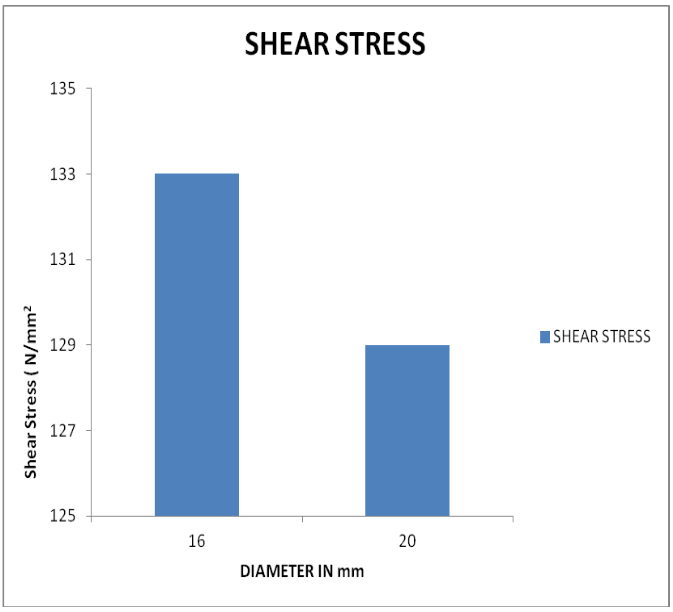

Fig: 14 Shear stress

From fig 14 and table 4 it is observed for LM6-18% -Ti-B specimen with increase in diameter of the specimen the shear stress value decreases.

4.5 TORSIONAL TEST

Shear properties of a given material is found out by conducting torsion tests. There are two types of shear stresses, one is called direct or transverse shear, and corresponds to the type of stress encountered in rivets, bolts, and beams. The other type shear stress is called pure or torsional shear and represents the kind of shear stress encountered in a shaft subjected to pure torsion. Direct or transverse shear tests are usually conducted to obtain a measure of shear strength for specific applications on the other hand, the torsion test is usually employed to evaluate the basic shear properties of a material. In usual torsion test, a specimen of solid circular cross section is subjected twisting moment by a torsion testing machine. At selected increments of load. The angle is measured for a given gauge length of the specimen from the torque and angle of twist readings.

The initial length and diameter of the specimen is recorded. Specimen is placed inside the shackles and mounted on torsion testing machine. Initially set the angle plate and the main scale reading to zero. Make sure that the alignment is perfect. A straight line is marked on the specimen with a chalk. Twisting moment is applied. Note down the value of torque for every 10 degree angle of twist till fracture. After the failure of the specimen, the final length of the specimen is measured using thread.

The general equation for torsion is given by: $T/J=G^{\theta}/L=\tau/r$, (r=d/2 in mm), T $= \pi d^3$ /12

For this study the specimen used is LM6-18% -Ti-B composite Figure 8541 shows the specimen before testing and after testing for torsion test.

Fig: 15 Torsional testing machine

TABLE5: Torsional Stress Values for LM6-18% -Ti-B specimen

Angle of twist θ	Torque, T N-m	Torsional stress, KN-M
1.91	0.3	7.79

Fig:16 Torsion test specimen before testing and after testing

5. CONCLUSION

The following conclusions were drawn from the study

i) Small boron additions to titanium alloys offer opportunities to engineer microstructures that could improve processibility and performance.

ii) Trace boron additions refine cast grain size by an order of magnitude.

iii) The presence of Ti-B precipitates restricts the grain growth at elevated temperatures, even above the beta transus.

iv) Grain refinement and grain stability offer the potential to develop affordable thermo mechanical processing paths for titanium alloys.

v) Small boron additions provide 20% increase in strength and modulus relative to the baseline while retaining good fracture-critical properties.

vi) Control of composition, processing, and thermo-mechanical processing, which influence the

Microstructure, were identified as key factors in the maturation of Ti-B alloys for fracture critical and aerospace applications.

vii) Finally we observed improving mechanical properties like tensile strength and impact strength, Torsional strength by varying wt % of Ti-B in LM6 base material.

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