Experimental Investigation on Mechanical behavior and Microstructural Characterization of AA7075 Reinforced with TiB_2 Particles Produced via Stir Casting Process

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ABSTRACT: Aluminium Metal Matrix Composites (AMMC) has been used in fields such as aerospace, automotive, marine and defense owing to its attractive benefits such as high strength to weight ratio, high ductility and corrosion resistance. The present work studies the mechanical and tribological behavior of AMMC specimens prepared adopting stir casting method by varying the weight percentage of titanium diboride (6%, 8%, and 10%) and also conducts microstrutural study. The results indicates that the increase in weight percentage of titanium diboride reinforcement in AMMC increases the mechanical and tribological properties measured such as tensile strength , hardness and wear resistance. Tensile strength increases by 27.63 % and hardness increases by 16.23% for reinforcement with 10% weight comparing to 6% reinforcement weight. The wear rate has got a considerable decrease with increase in weight percentage of reinforcement. The microstructural characterization reveals that uniform mixture is obtained through the stirring process of AMMC manufacturing.

Keywords – AA7075, Friction Stir Casting, SEM Analysis, Titanium Particles

Nomenclature

AMMC – Aluminium Metal Matrix Composite

EDM – Electric Discharge Machining

HMMC – Hybrid Metal Matrix Composite

MMC – Metal Matrix Composites

SiC – Silicon Carbide

TiC – Titanium Carbide

TiB_2 – Titanium Diboride

Al_2O_3 - Aluminium Oxide

B_4C - Boron Carbide

TiO_2 - Titanium Dioide

1. Introduction

Composite materials are the one which has two different materials combined together to act as a single material which has distinct properties than the property exhibited by them individually. Composite materials find applications in numerous fields such as aerospace, automotive, marine, defense and so on. The major advantages of composite materials include high strength to weight ratio, high corrosion and wear resistance, light weight , fatigue strength and more. Composite materials may be classified upon the types of matrix material used such as metal matrix, polymer matrix and ceramic matrix composites. Reinforcements are the one which are used along with the matrix material to improve the mechanical and tribological properties of the final composite part. Reinforcements may be added to the matrix material in different forms such as particulates, fibres and so on. The manufacturing of composites can be done by various methods such as friction stir processing, stir casting, compression moulding etc The present work considers metal matrix composites with aluminium as the matrix material and titanium diboride as the reinforcement material in the form of particulates added using stir casting process Metal matrix composites has grabbed the attention of many researchers due to its high stiffness and strength. Lot of research activities have been carried out by many researchers to analyze the effect of reinforcement addition in metal matrix composites around the world. V.RamakoteswaraRao et.al [1] conducted the optimization of process parameters involved such as sliding velocity, sliding distance and wt.% of reinforcement in the production of AMMC specimens. The authors have evaluated the hardness and wear resistance of the AMMC specimens reinforced with titanium carbide and the authors have observed that AMMC with 2 μm titanium particles have shown good mechanical and tribological than reinforcement weight percenatge.The authors have reported that the addition of titanium carbide as reinforce has increased the wear characteristics of the AMMC specimens. Veeravalli Ramakoteswara Rao et.al [2] conducted study about the mechanical and tribological properties of AA7075 – TiC composites under conditions such as heat treated and casted. The authors have concluded that at cast condition the specimens have exhibited low hardness, tensile strength and wear resistance than heat treated conditions The increase in addition of titanium particles as reinforcement have reduced the wear rate and coefficient of friction. B.Ravi [3] performed the fabrication and evaluation of mechanical properties such as yield strength, tensile strength, hardness, impact strength for the aluminium based metal matrix composites with SiC and TiC as reinforcement. The HMMC specimens have been prepared by adopting casting technique. The evaluation of mechanical properties conducted has revealed that addition of reinforcement particles at 5% of both SiC and TiC have increased the properties such as yield strength , tensile strength ,hardness and impact strength is found to be decreased. M. Ramesh et.al [4] investigated the mechanical and wear behavior of metal matrix composites reinforced with titanium diboride (TiB2) at different weight percentages. The authors have conducted experimental work to measure tensile strength, hardness, and wear resistance. The authors have studied the wear of composite specimens using pin on disc test. The addition of titanium particles with higher weight percentage (12%) have shown good improvement in both the mechanical and wear characteristics. The microstructural study has revealed more wear grooves irrespective of load, sliding distance and reinforcement weight percentage. Basithrahman and Abirami et.al [5] studied the tribological behavior of AA7075 hybrid composite prepared using stir casting method by using the reinforcement such as Al_2O_3, B_4C and TiO_2. The authors have created the HMMC by varying the weight percentage of Al_2O_3 as 3% , 6% , 9% and 5% weight is considered for B_4C and TiO_2 .The wear resistance founds to be increasing at higher percentage of Al_2O_3 by keeping B_4C and TiO_2 as 5%. The microstructural study through SEM analysis shows the uniformity of ceramic particles in the aluminium matrix.

2. Materials and Methods

2.1 AA7075

The present work considers AA7075 as the matrix material for preparing the composite specimen due to its potential application in the field of aerospace due to high strength to weigh ratio. AA7075 was developed as a secret material in the year 1935 by a Japanese company named as Sumitomo metal and it was introduced in the market during 1943 by Alcoa. The first commercial utilization of the AA7075 was done by the imperial Japanese navy for airframe production. It is available in different tempers such as 7075-0, 7075-T6, 7075-T651.AA 7075 can be identified in the commercial market by various trade names such as Zicral, Ergal, and Fortal Constructal.Aluminium alloys have extensive usage in the field of aerospace in making aircraft fittings, gears, shafts, missile parts, regulating valve parts etc. The typical application of AA 7075 alloy is with the nozzles and beams used in the intertank section of Space shuttle solid rocket boosters. AA7075 has numerous benefits when comparing to other grades of aluminium alloys due to the availability of the alloying elements zinc and copper which makes the material suitable for aerospace structural applications. The table 1 shows the chemical composition the AA7075 considered in the present study. The alloy can be tempered to attain an improvement in strength and other associated mechanical properties required in the making of aerospace structures. AA7075 has appreciable mechanical properties such as high strength, good ductility toughness and higher resistance to fatigue. It has more susceptibility to embrittlement due to the microsegregation nature than other aluminium alloys. The physical and mechanical properties of AA7075 have been listed in table 2

Table 1 Chemical Composition AA7075

S.No	Element	Percentage %
1	Cu	1.2-2
2	Cr	0.18-0.28
3	Mn	0.3
4	Mg	2.1-2.9
5	Si	0.4
6	Ti	0.2
7	Zn	5.1-6.1
8	Fe	0.5
9	Al	Balance

Table 2 Physical and Mechanical Properties of AA7075

S.No	Property	Value	Unit
1	Density	2.381	g/cc
2	Hardness,Vickers	175	HV
3	Ultimate Tensile Strength	572	MPa
4	Tensile Yield Strength	503	MPa
5	Modulus of elasticity	71.7	GPa
6	Thermal Conductivity	130	W/m-k
7	Melting Point	477-635	°C

2.2 Titanium

The present work considers titanium diboride (TiB_2) to act as the reinforcement material along with the aluminium matrix for the preparation of composite specimens for the experimental work. The element titanium is available in earth's crust and lithosphere along with number of mineral deposits. The extraction of titanium element can be done by krollm and hunter's process . Titanium is available in different variants by combining with oxygen and chromium to form oxides, chlorides such as titanium dioxide, titanium trichloride and titanium tetrachloride which finds applications in the manufacturing of pigments, catalysts, and smoke screens. Moreover titanium can be alloyed with different elements such as iron, aluminium, vanadium and molybdenum to produce components with lightweight without compromising the strength of the final part. Titanium is found to have numerous applications in aerospace industries by acting as potential reinforcements in making composite specimens along with AA7075 alloys. High corrosion resistance and strength to weight ratio are the two useful properties associated with titanium for its consideration in aerospace composite material applications. Table 3 shows the various properties of TiB_2 reinforcement used in the present study as reinforcement for AMMC.

Table 3 Various Properties of TiB_2 Reinforcement

S.No	Property	Value
1	Thermal expansion	8.6 µm/(m.K) (at 25ºC)
2	Thermal conductivity	21.9 W/(m.K)
3	Electrical resistivity	420 nΩ.m (at 20ºC)
4	Magnetic susceptibility	+153.0 $*10^{-6}$ cm^3/mol at (293 K)
5	Young's modulus	116 GPa
6	Shear modulus	44 GPa
7	Bulk modulus	110 GPa
8	Poisson ratio	0.32
9	Mohr's hardness	830-3420 MPa
10	Brinell hardness	716-2770 MPa

2.3 Stir Casting Process

The preparation of the Aluminium metal matrix composites can be prepared by two different methods such as powder metallurgy and stir casting process. The present work utilizes the stir casting process for making specimen made out of AA7075 reinforced with titanium particles with different composition for the evaluation of tensile strength, hardness, wear and microstructural characterization. The process involves heating the matrix metal to the required temperature and adding the reinforcement material in to the molten metal and the mixture is stirred well for specimen preparation.

3. Experimental Work

The present study has conducted the evaluation of tensile strength, hardness, wear characteristics and microstructural study of the aluminium based composite specimens with titanium diboride as reinforcement.

3.1 Specimen Preparation

The specimen for the conduction of tensile, hardness and wear testing of the composite specimens with aluminium as matrix material and titanium diboride as the reinforcement has been done by stir casting process. At the initial stage the AA7075 bar is cut into small pieces and the total weight is measured. AA7075 was taken with 400grams weight and 6% (24gram) of titanium diboride particles are taken for the addition as reinforcement. AA7075 is preheated in the range of 650^{o}C - 700^{o}C.At 700^{o}C the titanium particle is poured into molten AA7075 and stirred using stirrer at 600 rpm. The molten mixture is then poured into the desired mold. Then the mixture is kept for cooling for a certain period of time to solidify. The casted material is removed from the mold. Then the material is cut into desired shape as per standards with electric discharge machine (EDM).The material is then taken for different testing such as hardness, tensile, wear and microstructure (SEM) analysis. The same procedure has been repeated with different reinforcement weight percentages of titanium diboride such as 8%, and 10% along with the matrix material AA7075.

3.2 Experimental Work

The present work conducts tensile ,hardness and wear testing of the prepared composite specimens The specimens for the tensile testing have been prepared as per ASTM B 557:2006 a standard method for the tension testing of wrought and cast aluminium and magnesium alloys . The tensile testing specimens are fabricated with gauge dimensions of length 50mm and diameter 10mm .The prepared specimens are loaded in the universal testing machine to evaluate the tensile strength of the specimen at a constant speed of 2 mm/min . the data acquisition system connected to the machine records the experimental values and displays in the form of a graph . In case of hardness evaluation, the specimens were prepared as per IS 1501:2002, vicker's hardness testing machine has been used by applying a load of 5Kg for five minutes with a diamond indenter of 10mm . The test was carried out on 10 different locations of the specimen with varying reinforcement weight percentages to understand the variation of hardness in the prepared specimen. The wear testing of the specimen is carried out for a sliding velocity of 1m using a pin of 8mm diameter and 30mm height. The specimens have been cut using wire cut EDM from the casted composite. The wear test has been carried out by applying a load of 2 Kgf at a speed of 200 rpm with a track diameter of 100mm. The wear tests have been used to evaluate the tribological parameters such as wear produced, frictional force and temperature generated.

4. Microstructural Study

The microstrutural study of the composite specimens is done by using Scanning Electron Microscope (SEM). The SEM analysis is carried out to visually examine the uniformity obtained in the mixture by using the SEM equipment at different magnifications. The SEM images may be used to understand the internal microstructure of the prepared specimen and also the internal defects that are acting as the key factors for the failure of the specimen under different loading conditions. The present work has utilized SEM under different magnifications ranging between x100 – x2000 with the particle size ranging between 10µm to 100 µm.

5. Results and Discussion

5.1 Tensile Testing

The specimens subjected for the tensile testing has been tested until the specimen undergoes breaking with the applied load. The value of the tensile load applied over the specimen before specimen failure has been used for finding the tensile strength of the specimen. The figure 1 shows the displacement of the specimen for the applied load during tensile testing. The results obtained shows that the increase in weight percentage of reinforcement increases the tensile strength of the AMMC specimens. The tensile strength obtained from 10% of reinforcement is 21.6% higher than 6% of reinforcement.

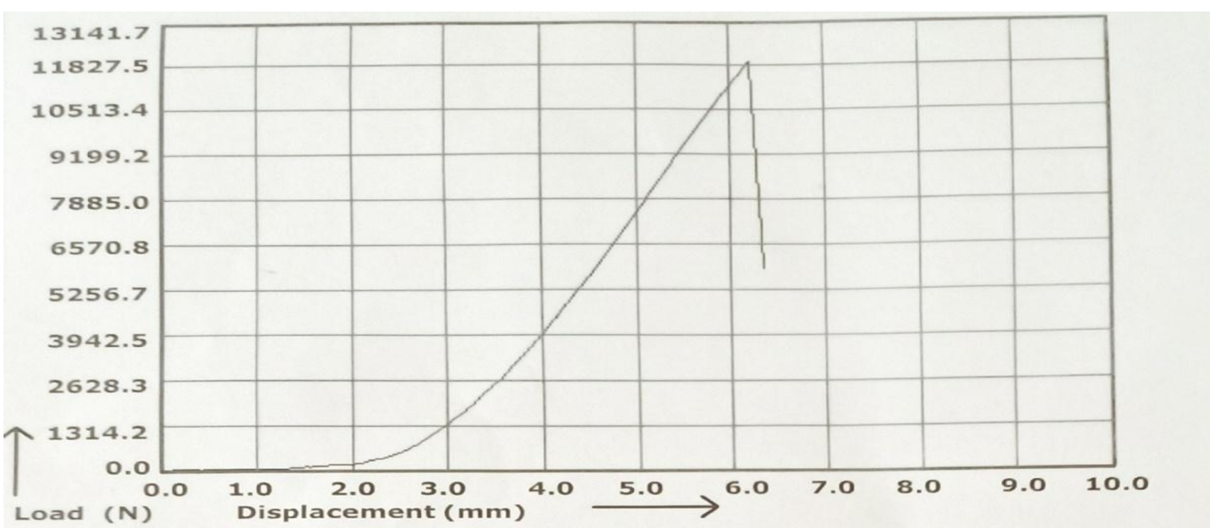

Figure 1 Load vs Displacement Graph for Tensile Testing

Figure 2 Failed Tensile Testing Specimen

Table 4 Tensile Testing Results

Weight %	**Tensile Load (N)**	**Tensile Strength (Mpa**
6	11947	175.15
8	13415	197.28
10	15202	223.56

The figure 2 shows the failed tensile testing specimen due to tensile loading. Table 4 represents the tensile testing results obtained for different reinforcement weight percentage

5.2 Hardness Testing

The test results of the hardness testing have been tabulated in table. The measured value of hardness in terms of HV has been obtained for all the three different weight percentages of the reinforcement. The value of hardness varies at 10 different locations considered for evaluation and also the increase in the weight percentage of reinforcements increases the hardness value. For the 6% weight of reinforcements added the hardness value ranged between 59 – 82 HV. In case of 8% weight the hardness value ranged between 60-82 HV. The highest value of hardness is obtained for the 10% weight of reinforcement where the hardness value ranged between 61 – 95 HV. Table 5 represents the measured hardness value of AMMC specimens.

Table 5 Hardness Value of AMMC Specimens

Trial No	Reinforcement Wt%		
	6%	8%	10%
	Hardness Value , HV		
1	71.3	78.2	82.2
2	72.1	82.6	93.1
3	75.6	75.6	81.7

4	74.3	78.5	82.5
5	72.7	76.3	79.9
6	71.8	74.2	78.8
7	70.9	76.3	77.1
8	59.3	60.2	61.1
9	69.2	72.5	75.9
10	81.3	88.3	94.5

5.3 Wear Testing

The wear study conducted has indicated that the wear resistance of the AMMC composites specimens increases with increase in the weight percentage of the reinforcement. The wear rate reduces with respect to the higher reinforcement present in the specimen and increase in hardness reduces the wear rate of the specimen. Figure 3 shows the wear in microns for 6% reinforcement weight.

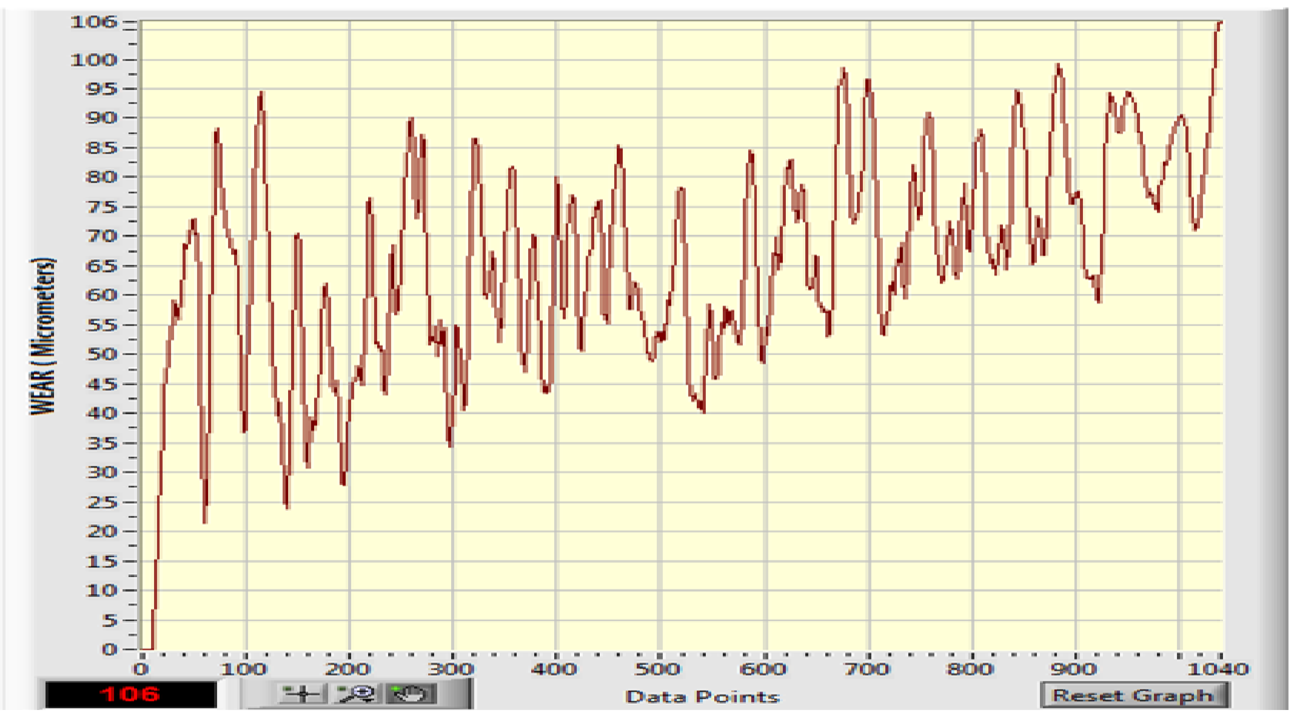

Figure 3 Wear of AMMC Specimen at 6% Reinforcement

5.4 Microstructural Characterization

The bonding between the matrix and reinforcement material is examined through SEM has revealed that the mixture created through the stirring of titanium diboride reinforcement particles with AA7075 matrix material has achieved a good uniformity The titanium diboride particles are uniformly distributed in the AA7075 matrix phase. The figure 4 (a) , (b) , (c) and (d) shows the micrographs created through SEM by different magnifications such as x100 , 1000 , x500 , x2000.

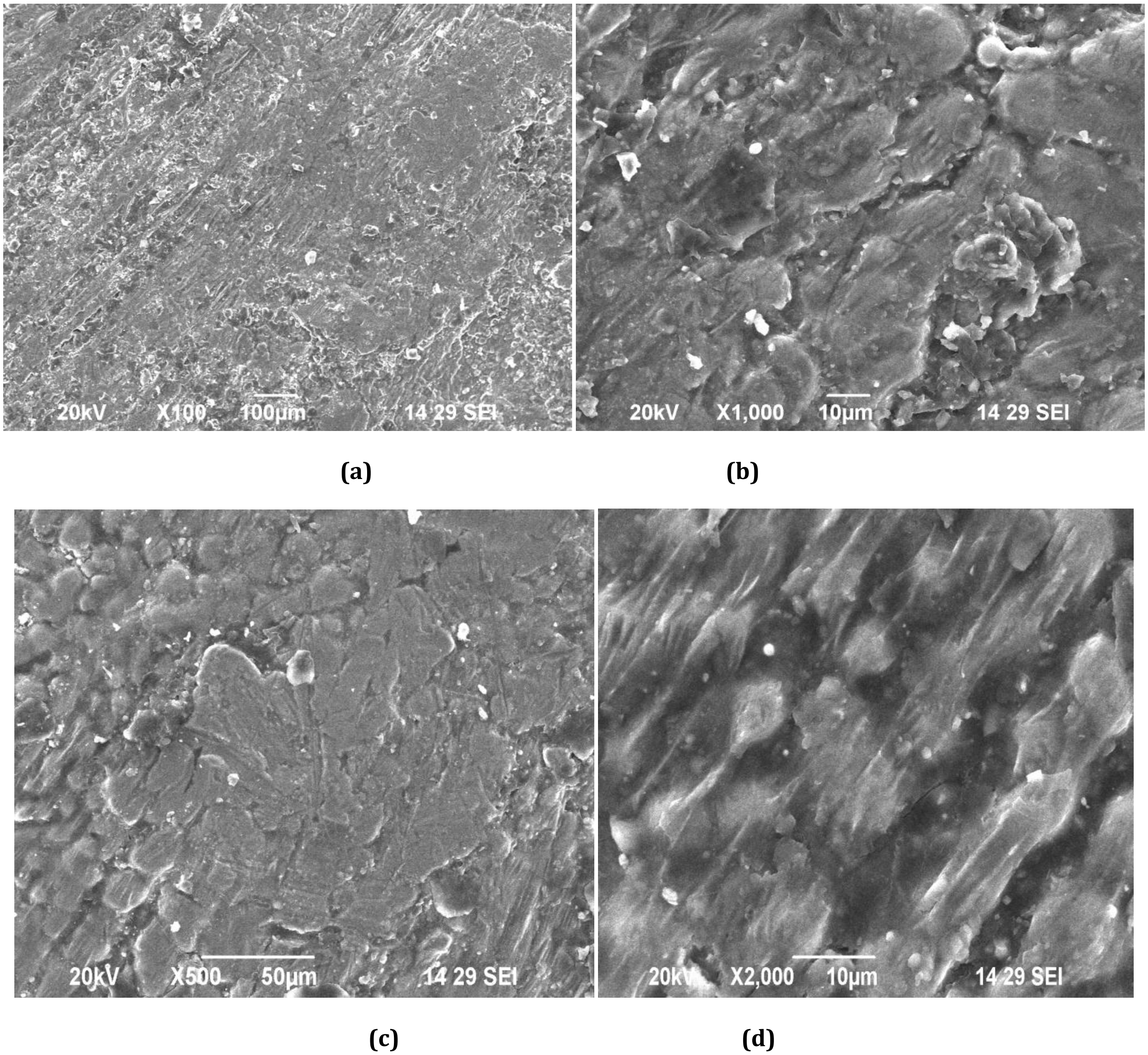

Figure 4 (a), (b), (c) and (d) SEM Micrographs of AMMC Specimens at magnifications x100, 1000, x500, and x2000

6. Conclusions

- The addition of reinforcement particles at different weight percentage has shown variation in the measured mechanical and tribological properties.
- The properties such as tensile strength, hardness and wear resistance increases with increase in the weight percentage of the reinforcement in AMMC prepared.
- The tensile strength of AMMC specimen increases by 27.63 % when the reinforcement added changes from 6% to 10%. and 16.23% improvement of hardness value is obtained for the increase in reinforcement from 6% to 10%.
- The wear resistance is higher in case of specimens with 10% titanium diboride than other specimens with lower weight percentage.
- The mixture obtained through the stir casting process is found to have very good uniformity between the AA7075 and Titanium diboride reinforcement particles.

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