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Influence of titanium carbide and activated carbon particles on the wear, mechanical properties and microstructure study of A413 metal matrix composite

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Present industries show an increasing demand in low-cost reinforcement and light weight composites. As compared to unreinforced alloys, metal matrix composites (MMCs) have possessed better properties including good thermal conductivity, wear resistance and high strength. The inexpensive low-density reinforcement of several discontinuous dispersions is available in huge quantities of agricultural waste is activated carbon (AC). Hence, the composites with activated carbon as reinforcement in Al-Si alloys (AMMC) are likely to find wide spread applications in aerospace, marine and automobile sectors. The current examination has been cantered at the usage of titanium carbide (TiC) and activated carbon (coconut shell ash powder) in micro form, with the aid of dispersing it into aluminium silicon alloy (A413) to yield composites *via* stir casting method. Hybrid reinforcement of 1, 2 & 3% of TiC and 5, 10 & 15 % of activated carbon *via* weight %, specimens have been prepared by using liquid metallurgy route. Tests like wear behaviour, mechanical tests and microstructure studies are executed and analysed. From the investigation it has been revealed that with increase in the % reinforcements of TiC and activated carbon improving the mechanical properties of the composites such as hardness and tensile strength. The microstructure pictures have revealed the distribution of TiC and AC reinforcement uniformly in the Al-Si matrix.

Keywords: TiC, AC, Al-Si matrix, wear, Mechanical properties

1 Introduction

The aluminium metal matrix composite possesses greater interest among MMCs in the application of aeronautical, automotive and marine industries. To enhance the mechanical properties of aluminium metal matrix it is reinforced by using variety reinforcement elements in the form of fibres, particles and whiskers. Ti, SiO_2, Al_2O_3, SiC and MgO are common nature of reinforcement used in the aluminium matrix based MMC. TiC, C, B_4C and C are also used as reinforcement with the aluminium matrix composites.

The incorporation of several different varieties of ceramic particulates in to single matrix has led to the improvement of hybrid composites. Development of hybrid metallic matrix composites has grown to be an important location of research hobby in Material science. Using a hybrid composite that includes variety of particulates, the gain of one form of particulate may want to complement to what is lacking inside the different. Now a days the use of agro-waste as a secondary reinforcement within the improvement of composites, is gaining greater importance. The advantages of the use of these agro-wastes are low value of the product and lower densities in assessment with ceramics (boron carbide or alumina).

The large recognition of A413 alloys (Al-Si) within the automobile sector branches from its remarkable casting characteristics such as true mechanical properties of higher resistance of corrosion, low thermal expansion coefficient, thermal conductivity is higher, higher strength to weight ratio and higher resistance to wear. In the production of casted components like cylinder liners, valve lifters, brake discs, engine blocks, pistons, *etc.*, the A413 alloy are specially used. With these applications, the demand for improve the property of wear resistance of these alloys have greater scope. The proposed work tries to acquire this on A413 alloys, with the use of grain refinements and modification.

To achieve better performance and properties of A413 alloys components; before casting, alloys are treated invariably with reinforcements for

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modification[1]. To convert the existing form of needle/large plate like morphology into eutectic silicon needle shaped structure in fine globular/fibrous eutectic silicon is done with modification[1]. Eutectic silicon modification can be carried out with any of the method like melt agitation in mushy state and melt injection by using some of the elements like Sb, Na, Sr, *etc.*, faster solidification, and mould vibration. Sr and Sb are the two well-known modifiers have yield good result in alteration of Si in hypoeutectic Al- Si alloys. From past investigation its revels that use of Sr as modifier reduces on higher melting time(melt holding time), on other hand with longer melt treatment time, Sb gives good results as better modification.

From last few years, many researchers focusing their attention on grain refinement. Grain refinements help in improving the mechanical and wear properties by acting on Al matrix and lead to fine equiaxed grain structure has been report by many researchers in their work. To get the combined effects of grain refinement and modification, with the addition of modifier and grain refiners to molten A413 alloys. Researcher's reports reveals that simultaneously addition of grain refinement and modifier gave better result for modification and grain refinement. But in actual industrial practice it is very challenging effort to control on the adding of percentage of separate modifier and grain refiner[1].

There is no clear literature occurs on the effect of addition of TiC and AC as master alloy utilised in the alteration of primary α-Al dendrites in A413 alloy on the wear resistance parameters. From this point, an attempt is made to investigate the influence of TiC and AC master alloys on the wear behaviour, mechanical properties and microstructure of A413 alloy.

The industries like automotive, marine and aeronautical in the recent years there is a significant increasing in the usage of Al-Si alloy. In last few years, researcher's focusing on the influence of grain refinement on composites. From the past investigation reveals that the mechanical and wear properties of alloys greatly improved with addition of grain refinement. The result of grain refinement indicates to create fine equiaxed grain structure in Al matrix[2]. to get better performance and properties in alloys, before casting it should be invariably treated for modification. We get fine fibrous/globular eutectic silicon on modification[3,4].

Combined effects of grain refinement and modification are acquired by the adding of modifiers and grain refiners to the molten Al-Si alloys[4-6].Adding of Al–Sr modifier and Al–Ti–B grain refiner as combined gives results in mutually killing of the effects of modification and grain refinement has been reported in past investigation[7, 8].

Sagstad and Bhondus[9] in their patented new master alloy, which gives in combined modification and grain refinement on Al-Si alloy with the addition of new master alloy of Al-Ti-B-Sr. the effect of Sr as modifier and B as grain refiner results in mutual poisoning with formation of SrB_6 compounds[10], from this it creates on adverse effect on modification and grain refinement. From the outcomes of Al-Ti-B-Sr, A K Prasadaetal[1,3] made investigation and developed with patented new master alloy as Al–5Ti–2C–15Sr, this master alloys plays a twin role in single stage as modifier and grain refiner when adding to Al-Si alloys. Zhao *et al.*[11] reported microstructure and synthesis mechanism of the master alloy.

Wear performance of Al-Si alloys is important parameters in industrial application and research; hence many researchers have made investigations on this parameters[12, 13]. In the Al-Si alloys, the % of Si content present in the alloy has greater influence on the wear resistance and same has been well reported. As compare to hypoeutectic and hypereutectic composition, Eutectic alloys are having better wear resistance and same has been investigated[13]. Using of Na and Sr as modifier to change the morphology of Si from needle/plate to globular/fibrous in Al-Si alloys. But, Pramila Bai *et al.*[14] stated in their work that this modification has little effect on the wear resistance of Al-Si alloy. Prasada Rao A.K *et al.*[1] reported that there is a noticeable development in weight holding capacity (seizure resistance) of the reformed alloy with a slight sacrifice of wear resistance and also they described that with use of grin refinement in Al-Si alloy will improves the wear resistance[15-20]. Sridhara *et al.*[21], work revels that the wear resistance increase with effect of the intermetallic particles adding to Al-Si alloy on parameter of wear rate at elevated temperature because formation of the glaze. There by a protection layer is formed and it avoids additional wear of the specimen[19-23.]

Wanwu Ding etal.[24] discussed on behaviour of adding Al-5Ti-C master alloy as grain refinement and it acts as primary and eutectic Si crystals modification in Al-20% Si. With the increasing concentration of master alloy, there is an improvement seen in mechanical properties of the alloys such as % elongation, UTS and BHN[24].

Konstantin *et al.* [25] works reported the use of nanoparticles grain refiners such as TiC, WC and SiC to modification of Al-Si alloys and investigate their mechanical properties. With the use of grain refiners, results in formation of fine structure in the grain size of the alloy. Hence there is an increasing of about 20-65% in % elongation of mechanical property of the modified casted alloy. The heat treated modified casted alloys also shows an increasing in its hardness value after the addition of grain refiners.

Shanawaz *et al.*[26] in his work indicated that the using of SiC and AC as grain refiners in composites production is providing better results in several applications. He stated that wear rate of the MMC increase with increasing of speed for given time and constant load condition.

Nithyanandhan *et al.*[27] investigation reported the using of reinforcement elements such as coconut shell ash microform and BC in the production of Al-Si alloy (6061) by stir casting process. He concluded with increase in weight % of reinforcement results in the increasing the values of hardness and tensile strength of alloy.

Mahesh L *et al.*[28] reported as development of the composites of aluminium reinforced with TiC and concluded with the experiments as TiC a grain refiner varies its content from 5 to 15 weight percentage, shows increased wear resistance.

In the proposed work an attempt is made to investigate the influence of Titanium carbide and Activated carbon powder as reinforcement on the mechanical properties, wear behaviour, and microstructure of the A413 alloy.

2 Experimental details

2.1 Materials

A413 alloy as a matrix and its chemical compositions are shown in Table 1, TiC and AC as reinforcements are obtained from Research & Development centre of mechanical engineering department. The chemical compositions of the reinforcements are shown in the Table 2 and 3.

2.2 Specimen preparation

- Known quantity of A413 alloy is heated to 720 °C in the induction furnace, after melting add Degasifier (Hexachlorothane) to the melt to remove the absorbed gases.
- Calculated amount of alloy (reinforcement) is added into the melt and stirring is done for the proper mixing of the master alloy.
- The cover flux of composition 45% NaCl+ 45% Kcl+10% NaF is added into the molten alloy, which forms the layer and prevents entry of further gases from atmosphere.
- After the addition of cover flux, melt is held for 5minutes (holding time)for the same temperature.
- Then melted alloy is poured into the sized pre heated graphite mould and allowed to cool to the room temperature.
- Prepare the test specimens for the required tests.

2.3 Wear studies

Wear tests were performed consistent with ASTM G99 standard. A computerized Pin-on-Disc wear test machine (Model: DUCOM TR20-PHM400) is used to conduct the wear test in dry sliding conditions. Maximum load capacity of machine is of 200 N; speed up to maximum of 2000 rpm and maximum diameter of track is 140 mm with tolerance measurement wear range of track is ± 2 mm. the specimens are made as per ASTM standard with dimensions values of length 30 mm and diameter 10 mm, the flat surface side of the sample must touch surface of the rotating disc. The surface roughness is in the range of 0.31 to 0.78 µm. The disc material is made from En-31 Steel (chemical configurations 0.019% P, 0.18% Si, 0.52% Mn, 0.13% Ni, 0.015 % S, 0.06% Mo, 0.14% C and 0.05% Cr) and 60 HRC of hardness value. The disc floor roughness in between 0.02 and 0.06 µm. throughout the work a constant

Table 1 — Chemical composition of A413 alloy.

Element	Si	Cu	Mg	Fe	Mn	Zn	Pb	Ti	Al
Weight (%)	12.5	0.10	0.10	0.6	0.5	0.1	0.1	0.2	85.8

Table 2 — Properties of TiC powder reinforcement.

Particle size (mesh)	Molecular weight (g/mol)	Melting (°C)	Density (g/cc)	Titanium (%)	Carbon (%)
325	59.87	3140	4.92	77.91	20.03

Table 3 — Properties of Activated carbon (coconut shell ash powder).

Particle size (mesh)	Atomic weight (g/mol)	Density (g/cc)	Carbon (%)	Moisture (%)	Ash (%)	Volatile mat. (%)	Chloride (9%)	Sulphate (%)	Iron (ppm)
80	12.1	0.58	88.92	2.22	1.50	7.06	0.01	0.01	300

track diameter of 100 mm is used. Using computerized data acquisition system, wear loss and tangential friction force are monitored and recorded.

The wear loss was measured in grams, frictional force by sensor recording and monitors the frictional force. The parameters like sliding speeds, sliding distance and varying normal pressure are used to conduct the wear test. For better results two trails are carried out for each specimen.

At room temperature, with various parameters like varying sliding distance values of 500 m,1000 m, 1500 m and 2000 m, varying sliding speed values of 200 rpm, 400 rpm,600 rpm and 800 rpm, varying load values of 14.7 N (1.5kg), 29.43 N (3.0kg), 44.15 N (4.5kg) and 58.8 N (6.0kg) test samples are examined. The different levels of composition of test samples are shown in the Table 4.

2.4 VickersHardness test

Hardness is distinct as the opposition to indentation. The measuring of permanent depth of the indentation gives the hardness value of the sample. The VHN test method consists of a diamond indenter used for indentation. it is of square base pyramid shape with an angle of 136° between opposite faces exposed to the test load of 1 kgf. Dwell/holding time 20 seconds used during the process. The two diagonals of the indentation present on the surface of the material after removal of the load are measured through the computer interface.

2.5 Tensile test

As per ASTM E8 standard, a gauge length of 400 mm and 8 mm diameter specimens are prepared to conduct tensile test. The yield stresses, ultimate tensile strength (UTS), % elongation, reduction in area are obtained using a computerized UTM.

2.6 Microstructure studies

To examine the microstructure of the specimen, the cast composite is cut into length of 15 mm and diameter of 25 mm. The cut specimen is finished with flat surface; fine grinding with emery, using fine abrasive powder the polishing of specimen is done and finally chemically etched. The microstructure study was observed under a Carl Zeiss optical microscope at magnifications ranging from 100X to 500X, after etching with 0.5% HF.

Table 4 — Intermetallic content.

Intermetallic content (wt.%)	A1	A413
	A2	A413+1TiC
	A3	A413+2TiC
	A4	A413+3TiC
	A5	A413+5AC
	A6	A413+10AC
	A7	A413+15AC
	A8	A413+1TiC+5AC
	A9	A413+2TiC+10AC
	A10	A413+3TiC+15AC

3 Experimental results

3.1 Wear tests

From Fig. 1, it is observed that as the reinforcement TiC percentage increases in alloys which influence the resistance to wear with decrease in the wear rate and is indicated in the composite A2, A3 and A4. Wear rate increases as load increases and then decreases in A3 the trend seems to be increasing in A4 alloy. With the increasing in sliding distance there is increasing wear rate in A2 and decreases in A3. From Fig. 2, it is noticed that as reinforcement AC percentage increases meantime the wear rate decreases, indicating that the composite A7 has a minimum wear. As the load increases mean time wear rate increases and then slips to constant in A6, further noticed that the trend increases in A7. As the speed increases wear rate decreases, indicating A5, A6 and A7 are good wear resistant composites. From Fig. 3, it

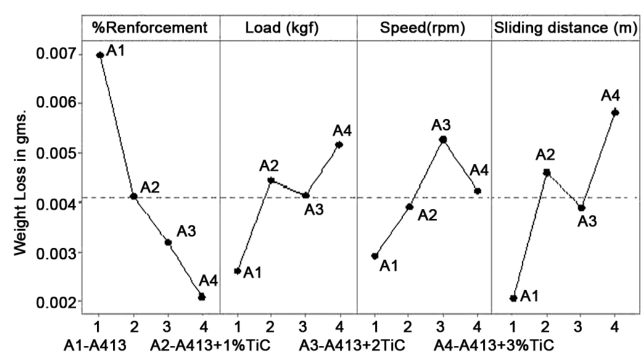

Fig. 1 —TiC as reinforcement.

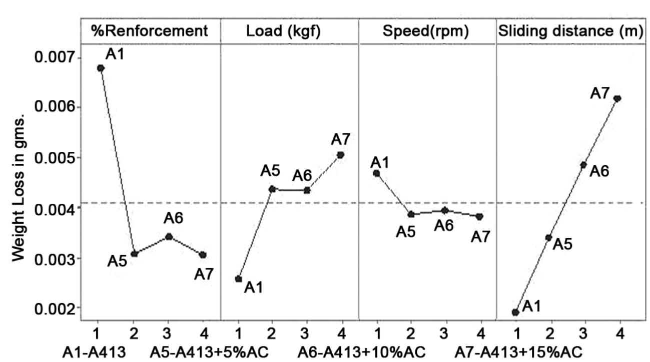

Fig. 2 — Activated carbon as reinforcement.

Table 5 — Results of yield stress, UTS, % elongation and VHN.

Alloys No.	Alloy composition	Yield stress (N/mm^2)	UTS in N/mm^2	% Elongation	VHN
A1	A413 (As cast)	176.69	221.749	1.375	73.54
A2	A413+1%TiC	186.68	229.759	4.680	74.74
A3	A413+2%TiC	180.22	229.600	4.860	84.58
A4	A413+3%TiC	175.05	228.917	5.260	76.58
A5	A413+5%AC	163.42	230.028	4.340	74.87
A6	A413+10%AC	217.33	256.378	2.560	94.40
A7	A413+15%AC	227.25	259.410	1.680	100.92
A8	A413+1%TiC+5%AC	163.57	223.447	4.900	77.53
A9	A413+2%TiC +10%AC	169.51	224.236	5.275	91.15
A10	A413+3%TiC +15%AC	166.92	225.404	5.500	99.29

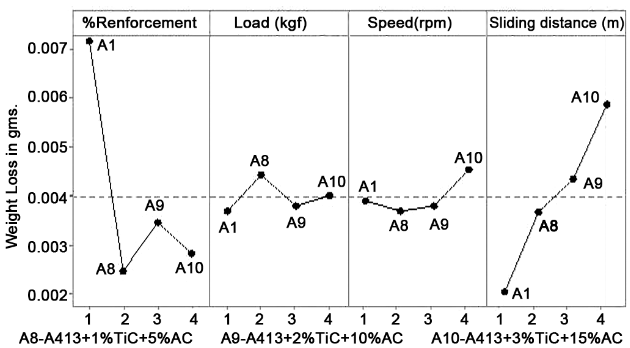

Fig. 3 — Combined reinforcement (TiC+AC).

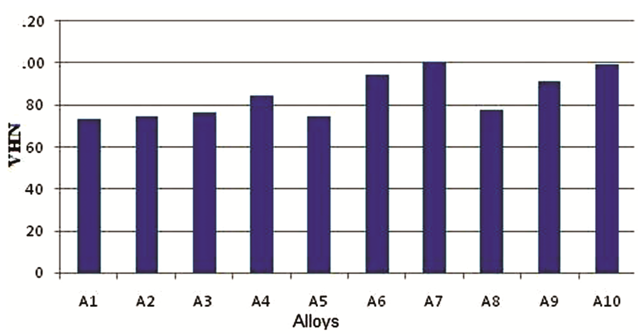

Fig. 4 — Hardness values.

is seen that the combined reinforcement percentage of (TiC+AC) increases leads to decreases in wear rate in A8, further it seems to be elevating. As the load increases, the wear rate in A8 increases and then decreases in A9, moreover it is also observed a small increase in wear in A10, With the increase in speed wear rate slightly decreased in A8 and found to be increased in A10 thus indicating increasing in sliding distance promotes increase in wear rate.

3.2 Vickers hardness test

Average Hardness values are taken from each specimen at four locations. Referred ASTM E 384-11 with the load of 1kg and dwell time is 20sec are shown in the Fig. 4.

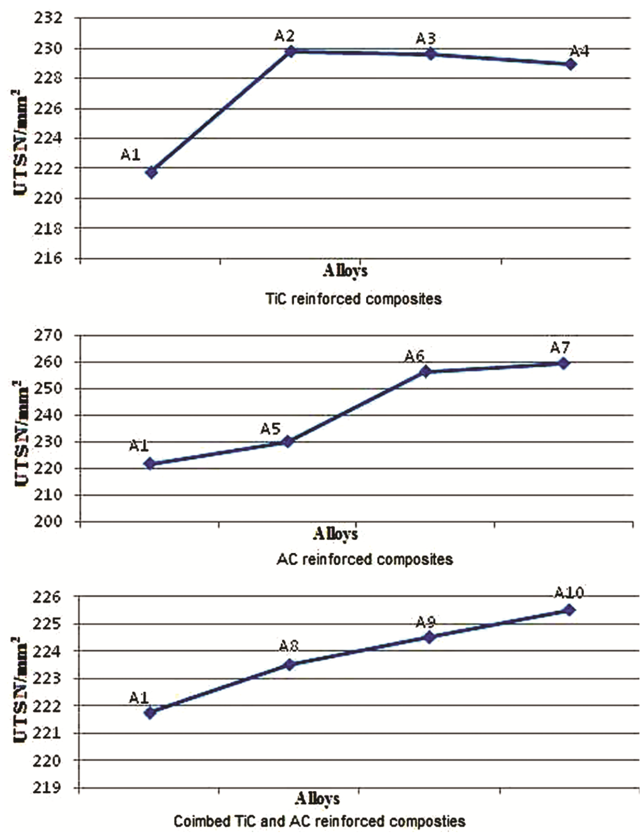

Fig. 5 — Tensile strength of different reinforcements.

3.3 Tensile test

The tensile test specimens of dia. 8 mm and gauge length 40 mm are prepared as per ASTM E8 standard. The yield stresses, ultimate tensile strength (UTS), percentage elongation, reduction in area are obtained using a computerized tensile testing machine.

3.3.1 Results of tensile and vickers's hardness test

From the Table 5 and Fig. 5, the ultimate tensile strength for A1alloy is 221.749 N/mm^2. By adding the master alloy TiC to the A1-Si alloy resulting in increase in UTS of A2, A3 and A4 alloy. The ultimate tensile strength for A1alloy is 221.749 N/mm^2 and by adding the master alloy AC to the A1-Si alloy resulting in increased UTS in A5, A6 and A7 alloys. The ultimate tensile strength for A1alloy is 221.749 $N/mm^2$and with combined master alloy TiC+AC resulting in marginal increase in UTS of A8, A9 and A10 alloys. The percentage elongation compared with as-cast is increased with TiC reinforcement. The percentage elongation compared with as-cast is decreased with AC reinforcement. The percentage elongation compared with as-cast is increased with combined TiC+AC reinforcement.

3.4 Microstructure study(ASTM E3-11, E407-07)

The samples are coarse with a series of emery papers from 240 to 800 grain size and polished with velvet cloth using alumina powder. It was observed under a Carl Zeiss Optical Microscope at magnifications of 500X, with 0.5% HF etching.

3.4.1 Observations

From the Fig. 6, The as cast A1 - Microstructure consists of fine, needle-like particles of eutectic silicon in a matrix of aluminium solid solution. A fewfine angular particles of primary silicon are also seen in A1 alloy.

The alloy A2 - Microstructure consists of fine, needle-like particles of eutectic silicon in an aluminium solid solution matrix. A number of angular particles of primary silicon are also seen. The distribution of TiC particles is observed in the aluminium silicon matrix. The granular columnar/α-Al dendrites into fine equiaxed grain structure are change by the effect of the grain refiner, resulting in higher ductility, higher tensile strength, and higher toughness.

The alloy A3 - The uniform distribution of TiC particles is observed in the aluminium silicon matrix. The fine equiaxed grain structure obtained from the coarse columnar/α-Al dendrites of composite with the adding of grain refiner, resulting in higher ductility, higher tensile strength, and higher toughness.

The alloy A4 - Distribution of TiC particles with increase in percentage results in uniform distribution in the aluminium matrix. The coarse columnar/α-Al dendrites into fine equiaxed grain arrangement are change by the effect of the grain refiner, and its effects in higher ductility, higher tensile strength, and higher toughness.

The alloy A5 - Microstructure consists of fine, needle-like particles of eutectic silicon in a matrix of aluminium solid solution. Angular particles of primary silicon are also seen. The distribution of AC particle in the aluminium silicon matrix is quit uniform. The coarse columnar/α-Al dendrites into fine equiaxed grain arrangement are change by the effect of the grain refiner, resulting in higher ductility, higher tensile strength, and higher toughness.

The alloy A6-The distribution of AC particles with increase in percentage results in uniform distribution in the aluminium silicon matrix. The coarse columnar/α-Al dendrites into fine equiaxed grain structure are change by the effect of the grain refiner, resulting in higher ductility, higher tensile strength, and higher toughness.

The alloy A7 - The distribution of AC particles with increase in percentage results in uniform distribution in the aluminium silicon matrix. The coarse columnar/α-Al dendrites into fine equiaxed grain structure are change by the effect of the grain refiner, resulting in higher ductility, higher tensile strength, and higher toughness.

The alloy A8 - Microstructure consists of fine, needle-like particles of eutectic silicon in a matrix of

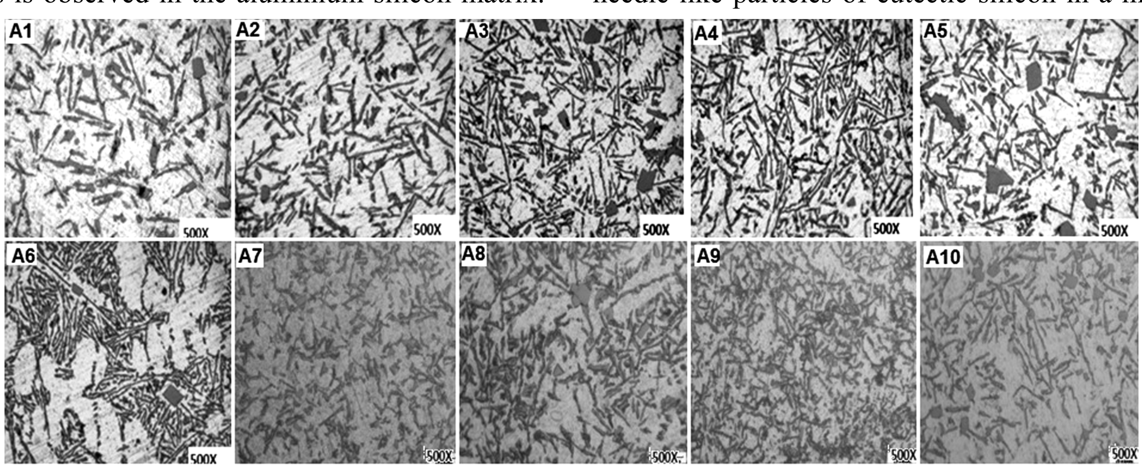

Fig. 6 — Microstructure.

aluminium solid solution. Dendritic patterns are seen with the eutectic silicon at the inter-dendritic regions.The combined distribution of TiC+AC particles in the aluminium matrix is quit uniform. The coarse columnar/α-Al dendrites into fine equiaxed grain structure are change by the effect of the combined grain refiner, resulting in higher ductility, higher tensile strength, and higher toughness.

The alloy A9 - The combined distribution of TiC+AC particlesin the aluminium matrix is uniform. The coarse columnar/α-Al dendrites into fine equiaxed grain structure are change by the effect of the combined grain refiner, resulting in improved tensile strength, improved toughness and ductility.

The alloy A10 - The combined distribution of TiC+AC particles in the aluminium matrix is more uniform. The coarse columnar/α-Al dendrites into fine equiaxed grain structure are change by the effect of the combined grain refiner, resulting in improved tensile strength.

4 Conclusions

As the increased percentage of TiC increases the wear resistances but the combined reinforcement with AC remarks with lowers the wear resistance.

(i) The VHN value of alloy A7 is the highest value as compared with the others.
(ii) UTS of alloy A7 results in the highest values as compared.
(v) It is suggested that the AC as a good reinforcement for the A413 alloy for improving the mechanical properties.
(iv) The microstructure study revealed the uniform distribution of TiC and AC reinforcement in the A413 matrix.

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