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FABRICATION AND CHARACTERIZATION OF IN-SITU REACTED AL-5TIC METAL MATRIX COMPOSITES

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ABSTRACT
Al-TiC composite is a wander engineering material which has been finding wide area of applications. Because of the formation of stable ceramic reinforcements (TiC), the in-situ metal matrix composites are found to exhibit excellent mechanical properties. In this paper, investigations on the fabrication, microstructure and mechanical properties of Al-5TiC composites reinforced with in-situ ceramic phases have been done and results presented. Some interesting conclusions of practical significance have been arrived at.

1. INTRODUCTION

The Al-TiC composites occupy a unique position in the family of metal matrix composites due to their excellent wear/stiffness, strength-to-weight ratio with good mechanical properties. The most common application of these composites is in commercial aerospace, defense and space technology, automobile, general industrial and engineering structures. Typical examples are found in helicopter blade, automotive piston, engine block, cylinder liners, motorcycle brake disk, etc [1,5].

Several processing technique have been developed to disperse discontinuous (particulates, whiskers, platelets) reinforcements uniformly in the matrix [1-3]. However, each fabrication technique has its own advantages and limitations. Some of the problems encountered are: residual micro porosity, uneven distribution of reinforcement, control of matrix-reinforcement interface, scaling up of the process for industrial utilization and processing cost. To overcome some of the inherent problems that are associated with conventionally processed materials, a new processing technique called, in-situ processing, has been developed. In-situ composite is the term applied to a relatively small, but fast expanding domain of materials where the reinforcing phase is formed within the parent phase by controlling melt growth, chemical reaction, transformation and deformation. In-situ process is cost effective and the interfaces produced are relatively stable and impurity-free.

The Al-TiC composite system has been studied by a number of researchers and has been found to possess good strength and stiffness. It has been reported that the TiC reinforced Al matrix composites exhibit higher stiffness and ductility than TiB_2 reinforced composites.

This may be attributed to the stronger interfacial bonding in the Al-TiC system due to the increased tendency for nucleation of solid on the particle surfaces [4,6,8]. Further research is needed to improve the mechanical properties such as wear and tensile strength of Al-TiC composites.

n the present work Al-5TiC composites have been fabricated and microstructure and mechanical properties such as wear and tensile strengths have been studied. It has been observed that Al-5TiC has better strength than other Al based composites having same volume fraction of reinforced particles. It has also been proved that interfacial bonding strength depends on the manufacturing route.

2. EXPERIMENTAL PROCEDURE

The in-situ process involves introducing carbon bearing activated charcoal into an Al-Ti melt, thereby forming TiC particles in the melt. In these experiments master alloys of Al-10Ti were prepared in an induction furnace at a temperature of 1200^0C and poured in graphite moulds to solidify. There after Al-10Ti master alloys were melted in a pit furnace at 1200^0C,1250^0C, 1350^0C and activated charcoal was added into the melt to meet stoichiometry of TiC (Ti : C) and held for 30 min, 20 min to complete the in-situ reaction for the formation of TiC particles. Degasser was used to remove the dissolved gas such as hydrogen from the melt. Flux was used to accelerate the reaction and to avoid the oxide formation. Experimental setup of an apparatus for fabricating in-situ Al-TiC composite is shown schematically in Fig.1.

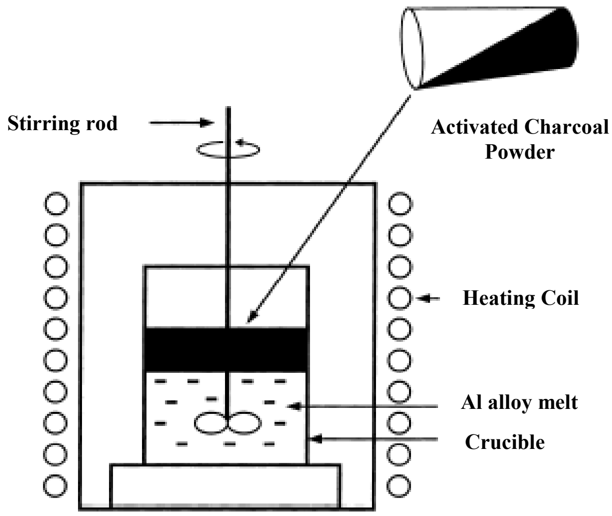


Fig.1: Schematic diagram of an apparatus for fabricating in-situ Al-5TiC composites.

3. EXPERIMENTS PERFORMED

(a) SEM, EDX and XRD studies: SEM micrographs, EDX and XRD peaks have been studied to ascertain the formation of TiC particles during in-situ reaction.

(b) DTA analysis: DTA analysis of Al-10Ti (as-cast) has been carried out in argon atmosphere from room temperature to 1400^0C with incremental rate of 10^0C/min in alumina crucible.

(c) Tensile and wear test: Al-5TiC composites have been tested for tensile and wear and results are tabulated.

(d) Rolling and forging of Al-5TiC were done and hardness values were tabulated.

4. RESULTS AND DISCUSSIONS

4.1 Microstructure Analysis

SEM photomicrographs of Al-TiC composite prepared at 1250^0C temperature and a reaction time of 30 min. (Fig.2a- b) show the presence of TiC particles of 0.5 µm sizes agglomerated in the grain boundaries of Al matrix. From the micrograph it has been observed that bigger size particles have a polyhedral morphology, while the smaller ones are globular. Al-TiC composites prepared at 1250^0C at 30 min. reaction time have globular morphology of TiC and same composites prepared at 1350^0C with 45 min. reaction time possess a polyhedral morphology (Fig.2c-d). The XRD and EDX microanalysis results confirm the composition and formation of TiC particulates. Al-TiC prepared at 1200^0C and 20 min reaction time shows the presence of needle shape Al_3Ti particles along with TiC particles (Fig.2e-f). The corresponding XRD and EDX microanalysis are shown in Figs.3 and 4.

4.2 Rolling and forging analysis

Al-5TiC composite produced at the reaction temperature of 1200^oC for 20 min. reaction time was cold and hot rolled at 350^oC with various percentages of reductions such as 40, 60, 80 and 90 using a single pass rolling mill. Hardness of the entire test specimen has been tabulated (Table-1). It has been absorbs that by increasing percentage reduction hardness increases in both the cases. But in hot rolling after 80 percent reduction there was no change in hardness.

Table-1: Hardness of Al-5TiC composites in cold and hot rolled condition at various reduction levels.

Serial Number	Percentage reduction	Hardness,VH5	
		Cold rolling	Hot rolling
1	40	44.38 ± 0.86	45.37 ± 0.94
2	60	51.15 ± 2.07	46.39 ± 0.73
3	80	53.68 ± 1.11	51.08 ± 2.25
4	90	56.62 ± 2.79	51.08 ± 1.89

Al-5TiC composite produced at the reaction temperature of 1200^oC for 20 min. reaction time was cold forged and hot forged at 350^oC at constant load of 25 tones using a hydraulic press. Fig.5(a) shows the SEM photomicrograph of Al-5TiC composite in as cast condition. In this case $TiAl_3$ particle of needle morphology has been observed and fine TiC particles have also been observed in the grain boundaries of Al. After cold forging the needle like Al_3Ti particles are disintegrated into a fine blocky shape particles and well distributed throughout the matrix (Fig. 5b). This needle shaped Al_3Ti particles become finer under the hot forged condition when compared to cold forged samples (Fig. 5c). When the same hot forged sample was reforged at the same condition, the Al_3Ti particles became much finer and well distributed in the matrix when compared to the previous condition (Fig.5d).It has been observed that the TiC particles were not affected during forging.

4.3 Mechanical Properties

Table-2: Tensile properties of Al-5TiC composites

S.No.	Materials	UTS (MPa)	% Elongation
1	Unreinforced Al	90	30
2	Al-5TiC with Al_3Ti	142	6.8
3	Al-5TiCwithout Al_3Ti	189	16.5
4	Al-5SiC(Ref.7)	155	6
5	*AA 3103,3003(Ref.9)	180	4

* chemical compositions of AA-Aluminium alloys are shown below:

AA (alloys)	Percentage composition								
	Fe	Si	Mg	Mn	Cu	Zn	Ti	Cr	Al
3103	0.7	0.5	0.3	1.2	0.1	0.2	0.1	0.1	Remainder
3003	0.7	0.6	--	1.2	0.2	0.1	0.1	--	Remainder

Table-2 reveals that the strength of Al-5TiC composite increases by 100% as compared to that of Al due to reinforcement with small amounts of TiC particulates. It has been observed that with the presence of Al_3Ti particles, Al-TiC composite becomes stronger by 50% but ductility decreases. Al-TiC composites have a ductility of 16.5% if Al_3Ti particles are absent; whereas it has a ductility of 6.8% when Al_3Ti particles are also present. Commercially available pure Al has a ductility of about 30%. Thus, Al_3Ti phase has a negative effect on plasticity of the composite but it has a positive effect on UTS. The experimental results have shown that the tensile strength of the composite with TiC is higher than the value of the composite with a lot of Al_3Ti particles. Moreover, improvement in tensile strength of the composite is accompanied by an increase of the ultimate tensile strength. Fracture surface of tensile specimen is shown in Fig. 6.(a-b) and it has been observed that in the case of Al-TiC composite containing Al_3Ti, there is a brittle fracture and the sample which is free from Al_3Ti has ductile nature of fracture.

4.3.2 Wear properties

It is well known that aluminum alloys exhibit poor seizure and wear resistance during sliding owing to their softness. Such drawbacks can restrict their uses in tribological environments. Generally, ceramic reinforcing phases, in the form of fibers, whiskers and particles, confirm a beneficial effect by improving the wear resistance property of aluminum alloys. In the present work involving reinforcements (TiC, Al_3Ti), the wear properties of Al-5TiC composite were investigated and are shown in Figs. 7 and 8. Fig. 7 shows that the cumulative wear curves do not reach steady stage at any load. Fig. 8 (a-d) reveals that with increasing test load, coefficient of friction increases. The increase in coefficient of friction with increase in load may be attributed to the formation of wear debris consisting of large volume of hard particles and silicide particles pulling out of the matrix during wear at the pin and disc interface.

5. CONCLUSIONS

1. Al-5TiC composites prepared by in-situ technique have better strength compared to other Al-base composites having the same volume fraction of reinforced particles.
2. Wear properties of Al-5TiC composites are better due to the presence of brittle Al_3Ti particles as well as hard TiC particles in the matrix.
3. Rolling and forging have no effect on TiC particles but these processes disintegrate long needle like Al_3Ti particles in to fine blocky shape particles.

6. REFERENCES

1. T. W. Clyne and P. J. Withers, An Introduction to Metal Matrix Composites, Cambridge University Press, U.K., 1993.
2. R. K. Everest and R. J. Arsenault, Metal Matrix Composites: Processing and Interfaces, Acadmic Press, U.S.A., 1991.
3. K. K. Chawla, Composites Materials: Science and engineering, Springer-Verlag, New Yark, 1987.
4. F. J. Humphreys, A. Basu and M. R. Djazeb, The microstructure and strength of particulate metal matrix composites, Proceeding, 12th Riso International Symposium on Material Science, Roskilde, Denmark,1991, pp 51-66
5. A. R. Kennedy and A. E. Karantzalie, The incorporation of ceramic particles in molten Al and the relationship to contact angle data., Material Science and Engineering – A, 264, 1999, pp 122-129.
6. A. R. Kennedy and S. M. Wyatt, Characterizing particle-matrix interfacial bonding in particulate Al-TiC MMCs produced by different methods, Composite Part A: Applied Science and Manufacturing, Vol 32, Issues 3-4, March-April 2001, pp 555-559.

7. Daibin Ge and Mingyuan Gu, Mechanical properties of hybrid reinforced aluminum based composites, Materials Letters, 49, 2001, pp 334–339
8. A. Albiter, A. Contreras, E. Bedolla and R. Perez, Structural and chemical characterization of precipitates in Al-2024/TiC composites, Composite Part A: Applied Science and Manufacturing, Vol 34, 2003, pp 17-24.
9. http://www.indal.com/sheetd.htm

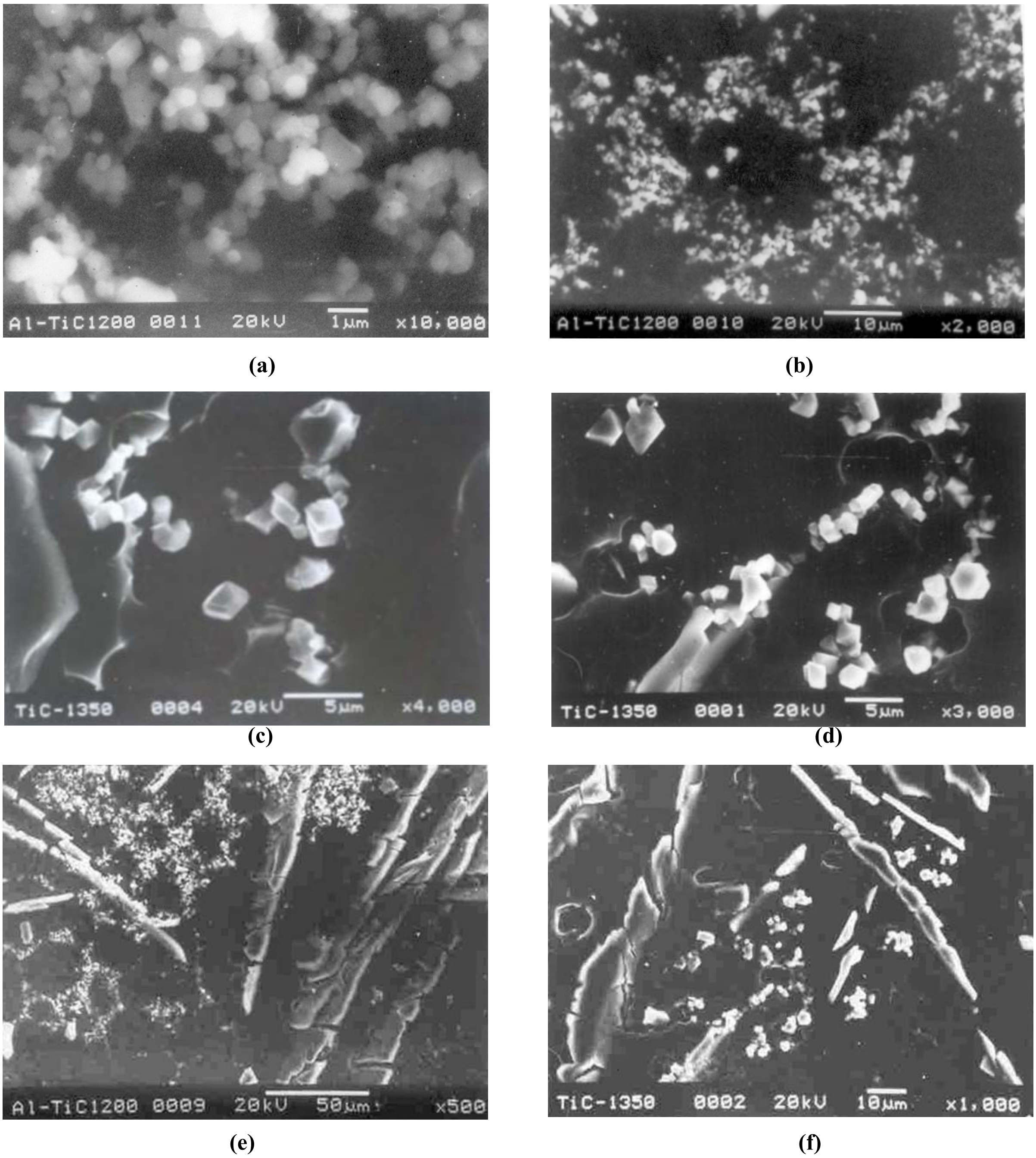


Fig.2: SEM photomicrographs of Al-TiC composite: (a) and (b) reaction temperature 1250°C and a reaction time of 30 min. (c) and (d) reaction temperature 1350°C and a reaction time of 45min. (e) and (f) reaction temperature 1250°C and a reaction time of 20 min.

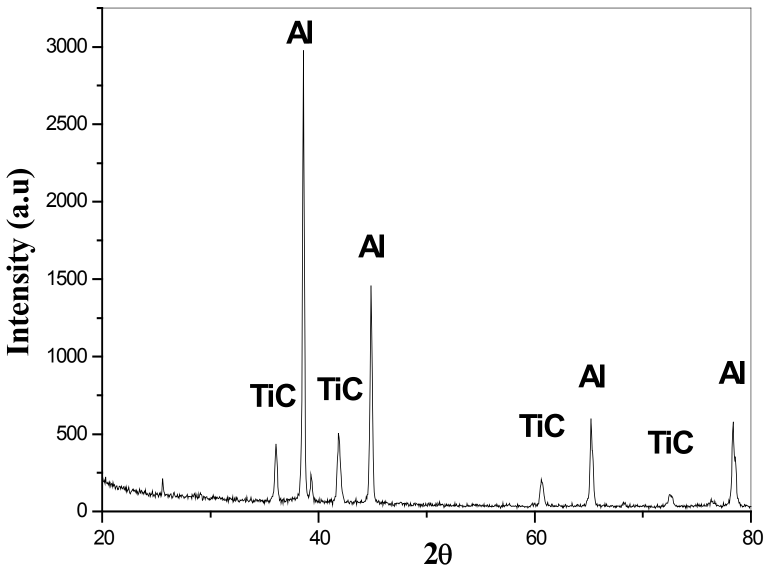
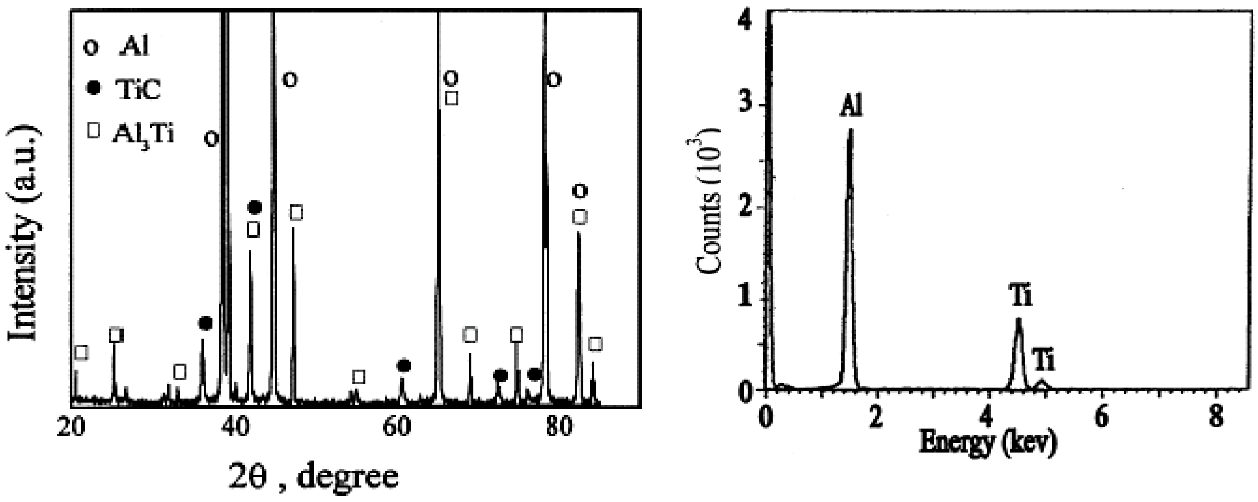
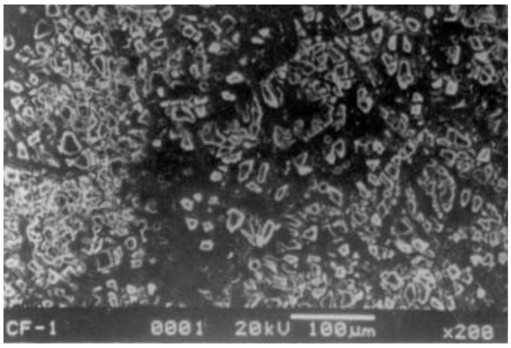


Fig. 3: XRD peak intensity of Al and TiC for the Al-5TiC composites

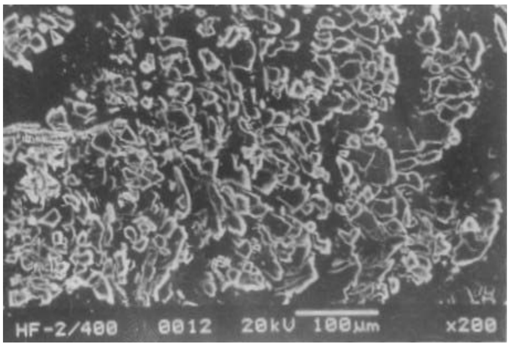


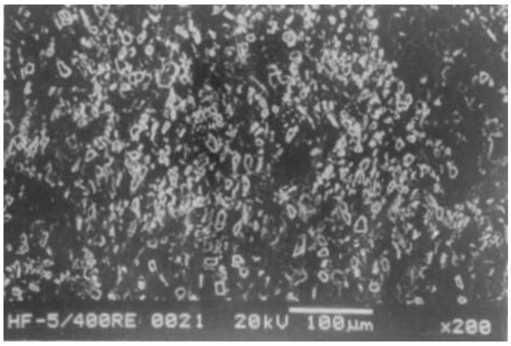
(a) (b)

Fig. 4: XRD and EDX showing: (a) presence of TiC, Al_3Ti and Al, (b) the bulk analysis of Al-5TiC composite



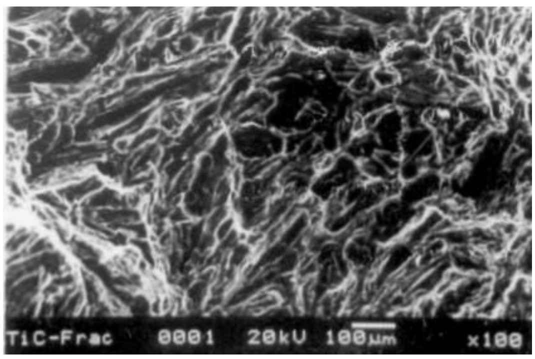
(a) **(b)**

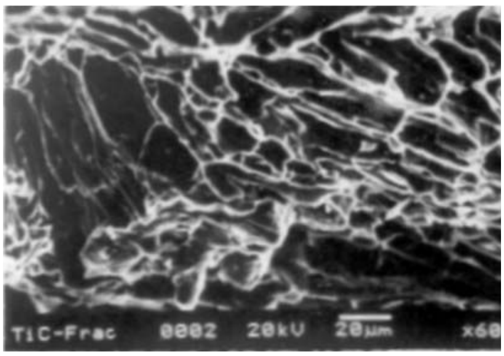




(c) **(d)**

Fig.5: SEM photomicrographs Al-5TiC composite (a) as cast condition (b) cold forged (c) hot forged at 400^{o}C (d) reforged at 400^{o}C.





(a) **(b)**

Fig.6: Fracture surface of Al-5TiC composite: (a) brittle fracture (b) ductile fracture.

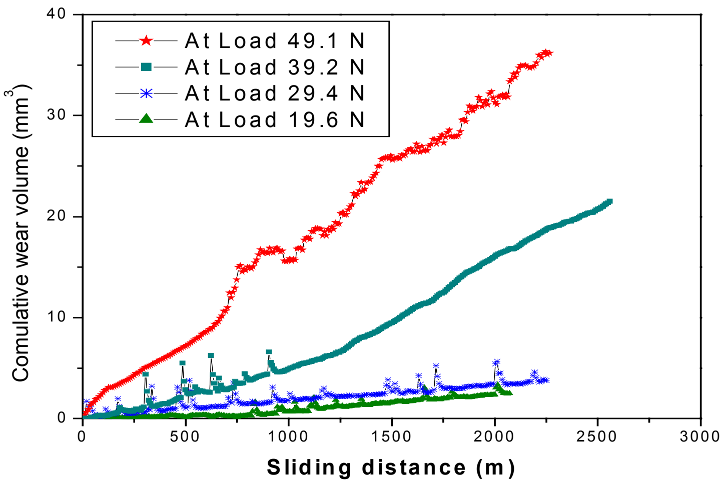


Fig.7: Cumulative wear loss of Al-5TiC composite at different loads (19.6N, 29.4N, 39.2N, 49.1N)

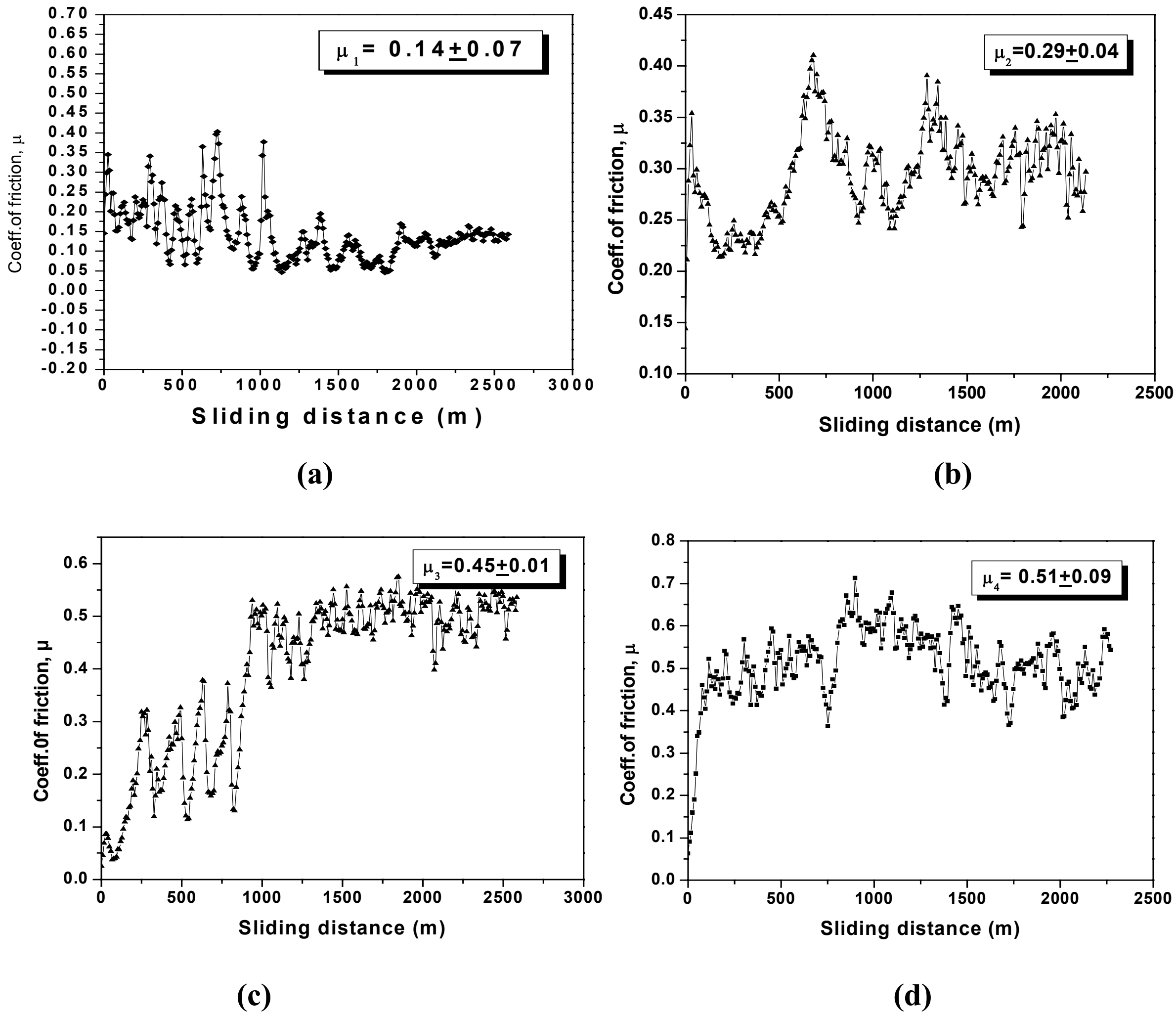


Fig.8: Variation of friction coefficient of Al-5TiC composites (μ) as a function of sliding distance: (a) 19.6 N load (b) 29.4 N load (c) 39.2 N load (d) 49.1 N load.