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Investigation of cutting force, surface roughness and flank wear in turning of In-situ Al6061-TiC metal matrix composite

D. Sai Chaitanya Kishore[a,] *, K. Prahlada Rao[b], A. Mahamani[c]

[a]*Department of Mechanical Engineering, Chiranjeevi Reddy Institute of Engineering & Technology, Anantapur, Andhra Pradesh, India.*
[b]*Department of Mechanical Engineering, Jawaharlal Nehru Technological University, Anantapur, Andhra Pradesh, India.*
[c]*Department of Mechanical Engineering, Sri Venkateswara College of Engineering and Technology, Chittoor, Andhra Pradesh, India.*

Abstract

Al6061-TiC composite with 2%TiC and 4%TiC were produced by the reaction of K_2TiF_6 and C with the molten aluminium. SEM and EDX tests were performed to know the presence of the TiC reinforcement. Vickers micro hardness test was done and find that the hardness was increased by the addition of TiC. Turning experiments were performed on 0, 2 wt % and 4 wt% of TiC reinforcement. The effect of process parameters such as cutting speed, feed rate and depth of cut on response cutting force, surface roughness and flank wear were studied during turning process. L25 Taguchi design was used for designing the experiments, from the analysis of means of the responses at all the levels it was found that addition of TiC reinforcement raises surface roughness and flank wear and reduces cutting force. The cutting force and surface roughness were less at higher cutting speeds. By the increase in cutting speed which increases the flank wear. The increase in feed rate and depth of cut increases cutting force, surface roughness and flank wear.

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Keywords: In-situ;SEM;EDX;micro hardness;

1. Introduction

There is always a scope of research in the fabrication of new materials, in the present scenario there is so much need in the development of lightweight materials with the properties like high strength, stiffness, hardness, fatigue and wear resistance. Metals are very useful in making different components and their properties can be improved by

* Corresponding author. Tel.: +91-9959545688
E-mail address: dskishore66@gmail.com

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adding reinforcement like B_4C, Al_2O_3, TiB_2, SiC and TiC e.t.c. Aluminium matrix composites (AMCs) are the competent material in the industrial world (2011). The AMCs are fabricated by different methods such as stir casting, squeeze casting, spray deposition, liquid infiltration, and powder metallurgy (2000). Casting route is particularly attractive as it is economical and practical (2006). The composite prepared by ex-situ method suffers thermodynamic instability between matrix and reinforcements, thus limiting their ambient and high temperature mechanical properties (2011). Ex-situ process possesses drawbacks like agglomeration, poor wetting and heterogeneity in microstructure (2000). Ex-situ composite fabrication method consists of many stages, like sorting, alignment, infiltration and sintering (2011). As in In-situ process the ceramic reinforcement is incorporated into the matrix by the chemical reaction of the halide salt with molten metal matrix. The in-situ formation of a ceramic second phase provides greater control of size and level of reinforcements, as well as the matrix reinforcement interface, yielding better tailorability of the composites (1997). In-situ composites are having advantages like they are more homogeneous in their microstructure and thermodynamically more stable and they also have strong interfacial bonding between the reinforcements and the matrices (2011). Applications of in-situ composites include wear parts for pumps, valves, chute liners, jet mill nozzles, heat exchangers, gun barrel liners (1991). Different reinforcements like TiB_2, ZrB_2, B_4C and TiC can be incorporated into the matrix by In-situ reaction. As several researchers did research on In-situ composites and found that halide salts plays a major role in the development of reinforcement in the metal matrix composites. Aluminium alloys have high strength at room temperature. The strength and other mechanical properties are reduced when the aluminium alloy is used at high temperatures. The above problem can be solved by incorporating TiC reinforcement into the aluminium matrix (2005). TiC is particularly attractive as it offers high hardness and elastic modulus, low density, good wettability yet low chemical reactivity with aluminium melts (2008). In-situ Al-TiC MMC was synthesized and properties like hardness, tensile strength and wear characteristics were studied by Natarajan et al. (2006). Mahamani et al. (2011) performed machinability study on Al-5cu-TiB_2 MMC. Birol et al. (2008) produced Al-TiC with different blends by varying the melt temperature and found that Al_3Ti particles were gradually replaced by TiC particles when the powder blend was heated above 800^oC. Birol (2008) performed SEM and XRD analysis and found that TiC particles apparently formed in increasing numbers with increasing reaction temperatures when Ti was introduced into molten aluminium in the form of a halide salt, together with graphite and the particle size also get reduces with the increased temperature. Mahamani (2011) fabricated Al-TiB_2 and performed EDX analysis and micro hardness testing and stated that hardness of the aluminium is increased by adding TiB_2 particles. Sai et al. (2013) did micro hardness test and find out that there was an increase in hardness by incorporating TiC particles. Mahamani et al. (2010) did multi response analysis on Al6061- TiB_2 by using grey relational analysis. Mahamani et al. (2012) did grey relational analysis for the responses flank wear, cutting force and surface roughness. Jha et al. (2013) studied the influences of machining parameters on Al-4.5Cu-TiC, in which TiC reinforcement was produced by the reaction of activated charcoal with titanium. As the present work mainly focused on to fabricate Al6061-2%TiC and Al6061-4%TiC composite by In-situ process by the reaction of K_2TiF_6 and graphite powder with the molten aluminum. An investigation was done on the hardness by the addition of the TiC particles to the Al-6061 by using micro hardness testing. Quantitative elemental analysis was performed by EDX testing to know the presence of TiC particles and SEM is performed to know the orientation and arrangement of the TiC particles. There was no work carried out on the effect of the cutting force and flank wear during the turning of in-situ fabricated Al-TiC composite material by the reaction of the halide salt, this makes to carry this research. In the present work an investigation has been done on the effect of cutting force, surface roughness and flank wear for different levels of cutting speed, feed and depth of cut for Al-6061, Al6061-2%TiC and Al6061-4%TiC.

2. Experimental work

2.1. Fabrication of Al6061-TiC

Fabrication of Al6061-2%TiC was carried out in a batch of 3 kg, for 2% TiC reinforcement 240.72 grams of K_2TiF_6 (Potassium hexafluorotitanate) and 15.6 grams of graphite powder was used (2006 & 2008). Al6061 was melted in crucible and premixed K_2TiF_6 and graphite powder of measured quantity were added to the molten aluminium and melt temperature was maintained as 900^o c. The molten material was held for 30 minutes and the melt was stirred at regular intervals during this exothermal reaction will take place between the molten aluminium and halide salt K_2TiF_6. The reaction between the salt and molten aluminium releases Ti, the solute Ti reacts with C to produce TiC particles and this happens by holding the melt for 30 minutes. After 30 minutes the slag is removed from the molten mix and the molten mix is poured into the cast iron mould. Fig.1 shows fabricated composite rod. Similarly Al6061-4%TiC was fabricated by using proper ratios of K_2TiF_6 and C.

Fig. 1. Fabricated composite rod with 2%TiC

2.2. Characterization of Al6061-TiC

EDX and SEM tests were performed on F E I Quanta FEG 200 - High Resolution Scanning Electron Microscope. Micro hardness test was performed on Vickers hardness testing machine. The test specimen prepared for SEM and EDX testing were circular in shape and the dimensions are 8 mm in diameter and 8 mm in thickness. The test specimen was well polished by using belt grinder and disc polisher. Fabricated composite was examined under scanning electron microscopy (SEM) to ascertain the formation of TiC particles and their distribution. Fig.2 and Fig.3 shows scanning electron micrograph of the fabricated Al6061-2%TiC and Al6061-4%TiC composite material. The SEM image discovers the presence of TiC particles in the aluminium matrix. The size of the reinforcement particles are less than 1µm. Quantitative elemental analysis is performed by EDX testing to know the presence of

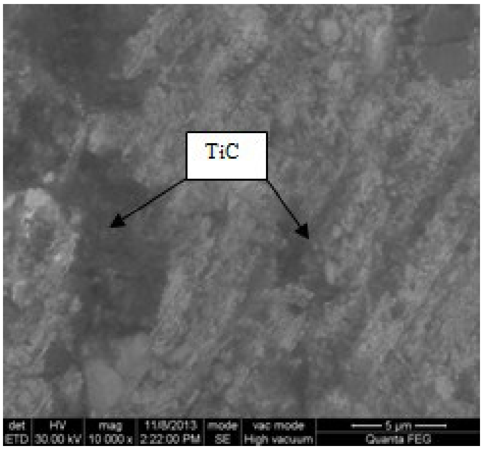

Fig. 2. SEM image for Al6061-2%TiC

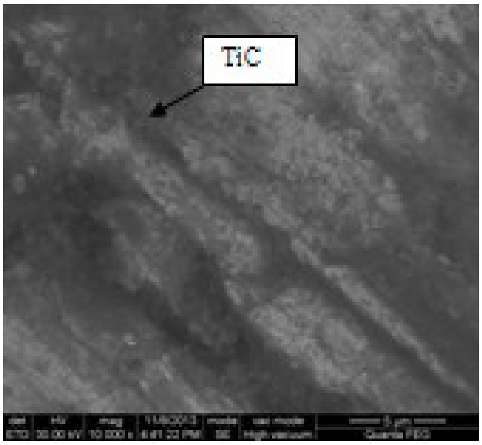

Fig. 3. SEM image for Al6061-4%TiC

TiC particles. Fig.4 shows EDX spectrum of the Al6061-2%TiC composite. Fig.4 shows the presence of Al, Ti and C particles in the fabricated Al6061-TiC composite. To know the improvement of hardness in the fabricated Al6061- TiC composite micro hardness test was performed at a load of 300 grams with 15 seconds dwell time. The average hardness of the aluminium 6061 was 54.3 HV, by the addition of the TiC reinforcement to the matrix the average hardness of Al6061-2% TiC was increased to 58.8 HV. Hardness values of the Al-6061, Al6061-2%TiC and Al6061-4%TiC composite were given in Table.1.

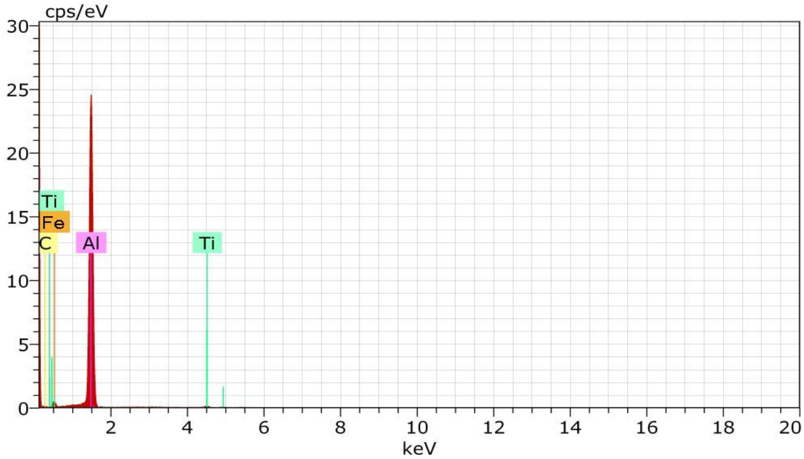

Fig. 4. EDX analysis for Al6061-2%TiC

Table 1. Micro hardness

Material	Trial 1	Trial 2	Trial 3	Average Hardness(HV)
Al6061	54.4	56.0	52.7	54.3
Al6061-2%TiC	60.8	57.7	57.9	58.8
Al6061-4%TiC	60.9	65.4	62.0	62.7

2.3. Experimental details

Turning experiments were carried out on Kirloskar made Turnmaster-35 lathe. Tool insert and tool holder specifications were given in Table.2. The cutting force was measured by Kistler dynamometer (model no 9857B) and charge amplifier model was 5070A. Turning experiments were done for 1 minute for each trial. Surface roughness was measured by using surface roughness tester made by Mitutoyo (model no SJ-210). Flank wear was measured by using tool maker’s microscope. The setup of lathe and lathe tool dynamometer was shown in Fig.5. All the turning experiments were performed in dry conditions.

Table 2. Tool and tool holder specifications

Component	Specification
Tool insert material	Uncoated tungsten carbide
Tool holder	PSBNR-2525M12
Tool insert	SNMG120408 MTTT5100

2.4. Experimental plan

Taguchi’s design of experiments is a tool to design and conduct experiments with minimum resources. An orthogonal array L25 for three factors was selected for the present research. This array has twenty five rows and each row represents a trial condition with factor levels. The vertical columns correspond to the factors specified in the study and each contains five levels like level 1, level 2, and level 3, level 4 and level 5 (a total of twenty five conditions) for the factor assigned to the column. The process parameters and their levels were shown in Table.3.

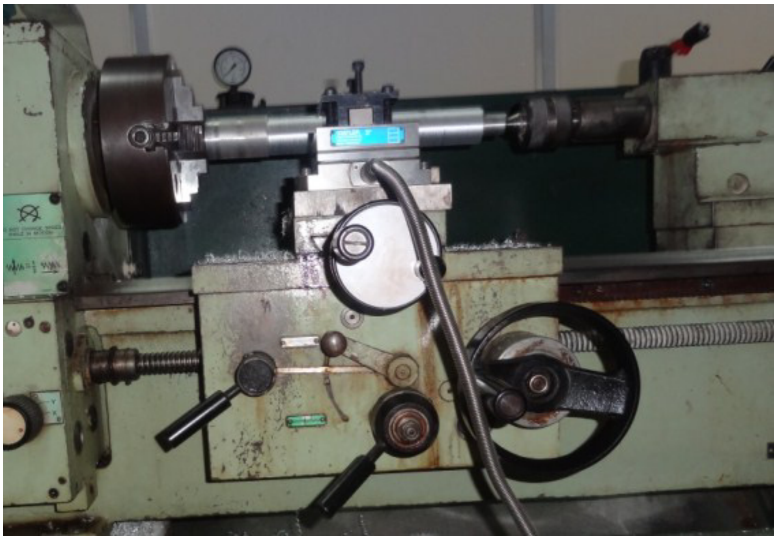

Fig. 5. Experimental setup of Lathe and Lathe tool dynamometer

Table 3. Process parameters

Process parameter	Level 1	Level 2	Level 3	Level 4	Level 5
Cutting speed(m/min)	40	60	80	100	120
Feed rate(mm/rev)	0.04	0.06	0.08	0.1	0.12
Depth of cut(mm)	0.5	0.75	1	1.25	1.5

3. Results and discussion

The experiments were conducted based on the planed design and the effects of cutting force, surface roughness and flank wear were recorded for Al6061, Al6061-2%TiC and Al6061-4%TiC, these results were tabulated in Table.4, Table.5 and Table 6. From the experimental results overall means of the response cutting force, surface roughness and flank wear were estimated by using minitab-16 for all the 5 levels of cutting speed, feed rate and depth of cut. Fig.6 shows the effect of cutting speed on the means of the cutting force during turning of the Al6061, Al-2%TiC and 4%TiC metal matrix composites, from Fig.6 it was observed the cutting force is larger in Al-6061 than that of 2% and 4% TiC reinforcements and cutting force was decreased by the increase in TiC reinforcement ratio. Increase in the reinforcement will minimize the build-up edge (2011), which reduces the cutting force. Cutting force is reduced by increase in cutting speed. Increase in cutting speed will reduce chip tool contact length which results reduced cutting force. Fig.7 shows the effect of feed rate on the means of cutting force for all the five levels of feed rate, the cutting force was reduced by increasing reinforcement ratio and the increase in feed rate increases the friction between tool and work piece (2011), which increases the cutting force. Fig.8 shows the effect of depth of cut on the means of the cutting force, the cutting force was high in Al-6061 i.e in 0%TiC and it was less at 4%TiC. The increase in depth of cut increases cutting force due to increase in contact area. Fig.9 shows the effect of cutting speed on the means of surface roughness, as the Fig.9 shows that surface roughness was increased by increase in TiC reinforcement as during the machining of harder TiC particles generates increase in cutting temperature which results increase in surface roughness. Increase in cutting speed reduces build-up edge formation and this result lower surface roughness at higher cutting speeds. Fig.10 shows the effect of feed rate on the means of surface roughness, the surface roughness was increasing by increase TiC reinforcement ratio. Fig.10 shows that surface roughness was increasing by increase in feed rate. Fig.11 shows that surface roughness value was higher in 4%TiC and the increase in depth of cut generates higher build-up edge and became a cause in increase in surface roughness.

Table 4. Experimental results for turning of Al-6061

Exp.No	Cutting speed(m/min)	Feed rate(mm/rev)	Depth of cut(mm)	Cutting force(N)	Surface roughness(µm)	Flank wear(mm)
1	40	0.04	0.5	133.03	2.115	0.01
2	40	0.06	0.75	137.45	2.169	0.02
3	40	0.08	1	140.2	2.284	0.04
4	40	0.1	1.25	234.88	2.697	0.05
5	40	0.12	1.5	449.24	2.736	0.06
6	60	0.04	0.75	92.36	2.097	0.03
7	60	0.06	1	136.35	2.325	0.05
8	60	0.08	1.25	168.54	2.37	0.06
9	60	0.1	1.5	369.81	2.483	0.07
10	60	0.12	0.5	124.98	1.946	0.04
11	80	0.04	1	75.03	1.718	0.05
12	80	0.06	1.25	134.06	1.954	0.06
13	80	0.08	1.5	237.6	2.441	0.08
14	80	0.1	0.5	110.33	2.379	0.06
15	80	0.12	0.75	165.43	2.582	0.09
16	100	0.04	1.25	82.04	1.556	0.07
17	100	0.06	1.5	157.22	1.949	0.09
18	100	0.08	0.5	58.46	1.74	0.07
19	100	0.1	0.75	130.63	1.956	0.08
20	100	0.12	1	195.02	2.395	0.09
21	120	0.04	1.5	110.94	1.659	0.09
22	120	0.06	0.5	65.56	1.438	0.06
23	120	0.08	0.75	98.29	1.634	0.08
24	120	0.1	1	121.48	1.902	0.1
25	120	0.12	1.25	136.75	2.213	0.11

Table 5. Experimental results for turning of Al6061-2%TiC

Exp.No	Cutting speed(m/min)	Feed rate(mm/rev)	Depth of cut(mm)	Cutting force(N)	Surface roughness(µm)	Flank wear(mm)
1	40	0.04	0.5	67.54	2.159	0.03
2	40	0.06	0.75	91.76	2.191	0.04
3	40	0.08	1	109.92	2.354	0.05
4	40	0.1	1.25	194.7	2.807	0.06
5	40	0.12	1.5	413.99	2.676	0.08
6	60	0.04	0.75	59.27	2.192	0.05
7	60	0.06	1	81.77	2.331	0.07
8	60	0.08	1.25	144.99	2.579	0.08
9	60	0.1	1.5	270.51	2.576	0.09
10	60	0.12	0.5	109.6	2.011	0.05
11	80	0.04	1	57.77	1.751	0.06
12	80	0.06	1.25	105.73	2.076	0.07
13	80	0.08	1.5	164.35	2.530	0.09
14	80	0.1	0.5	76.54	2.519	0.08
15	80	0.12	0.75	122.02	2.621	0.1
16	100	0.04	1.25	67.94	1.476	0.08
17	100	0.06	1.5	144.04	1.988	0.1
18	100	0.08	0.5	54.08	1.757	0.09
19	100	0.1	0.75	95.98	2.137	0.1
20	100	0.12	1	121.47	2.530	0.11
21	120	0.04	1.5	88.81	1.749	0.1
22	120	0.06	0.5	51.85	1.525	0.07
23	120	0.08	0.75	65.83	1.646	0.1
24	120	0.1	1	108.31	1.928	0.11
25	120	0.12	1.25	128.94	2.293	0.12

Fig.12 shows the effect of cutting speed on the means of flank wear for all the 5 levels of cutting speed, from the Fig.12 it was observed that flank wear was increased by increase in cutting speeds, at high cutting speed the

Table 6. Experimental results for turning of Al6061-4%TiC

Exp.No	Cutting speed(m/min)	Feed rate(mm/rev)	Depth of cut(mm)	Cutting force(N)	Surface roughness(µm)	Flank wear(mm)
1	40	0.04	0.5	63.86	2.248	0.04
2	40	0.06	0.75	76.89	2.237	0.05
3	40	0.08	1	107.44	2.580	0.06
4	40	0.1	1.25	181.99	2.965	0.07
5	40	0.12	1.5	373.54	2.957	0.1
6	60	0.04	0.75	53.51	2.303	0.06
7	60	0.06	1	77.39	2.306	0.09
8	60	0.08	1.25	151.02	2.817	0.1
9	60	0.1	1.5	238.13	2.702	0.12
10	60	0.12	0.5	95.42	2.050	0.07
11	80	0.04	1	51.37	1.993	0.07
12	80	0.06	1.25	92.32	2.203	0.08
13	80	0.08	1.5	151.75	2.653	0.11
14	80	0.1	0.5	71.2	2.582	0.1
15	80	0.12	0.75	111.87	2.629	0.12
16	100	0.04	1.25	65.68	1.570	0.09
17	100	0.06	1.5	128.66	2.067	0.11
18	100	0.08	0.5	49.76	1.997	0.1
19	100	0.1	0.75	84.42	2.276	0.11
20	100	0.12	1	120.36	2.821	0.13
21	120	0.04	1.5	84.89	1.876	0.11
22	120	0.06	0.5	58.89	1.543	0.09
23	120	0.08	0.75	61.49	1.660	0.11
24	120	0.1	1	96.5	1.941	0.12
25	120	0.12	1.25	124.56	2.455	0.14

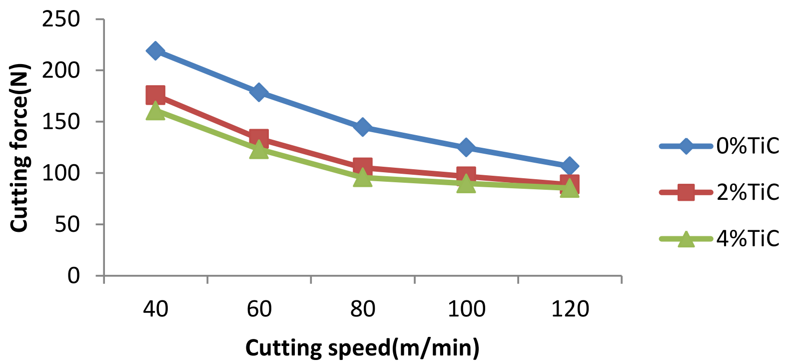

Fig.6. Effect of cutting speed on means of cutting force

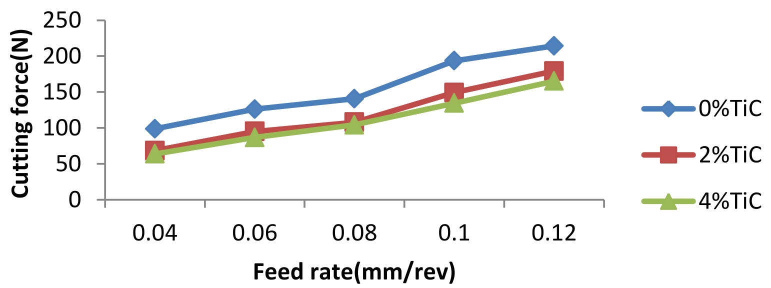

Fig.7. Effect of feed rate on means of cutting force

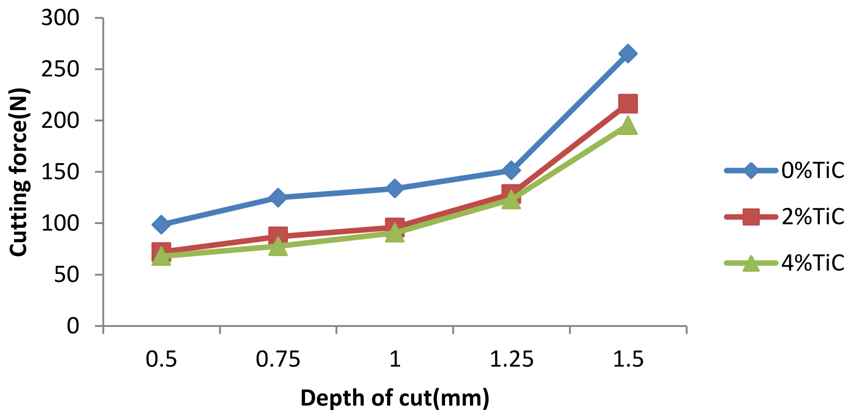

Fig.8. Effect of depth of cut on means of cutting force

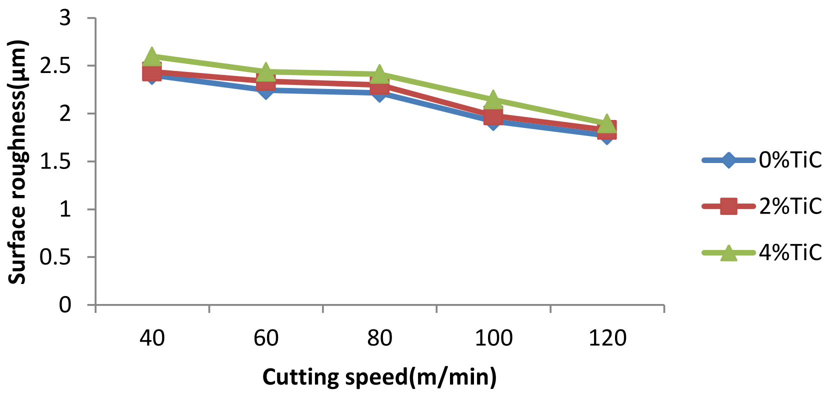

Fig.9. Effect of cutting speed on means of surface roughness

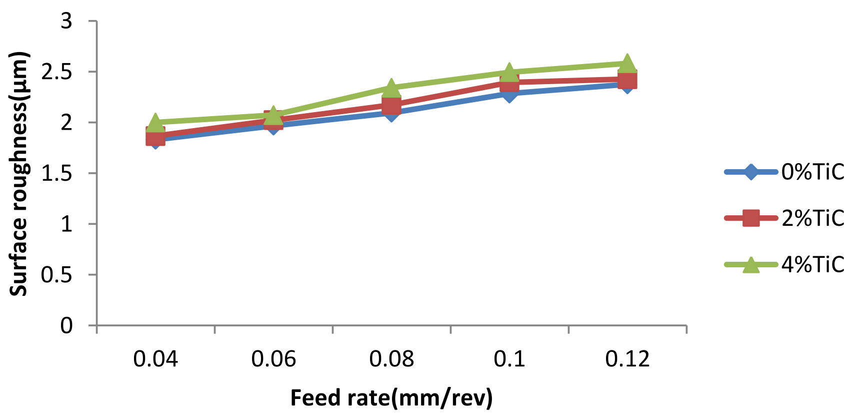

Fig.10. Effect of feed rate on means of surface roughness

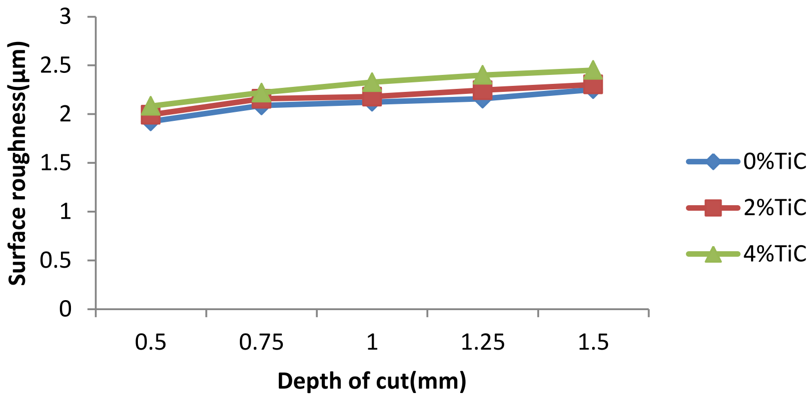

Fig.11. Effect of depth of cut on means of surface roughness

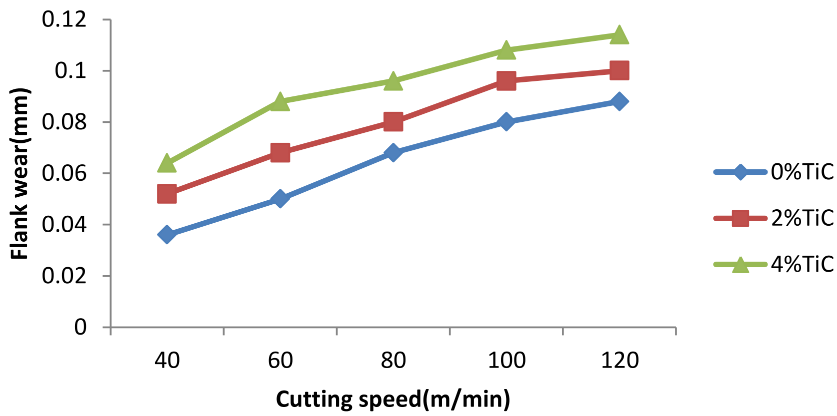

Fig.12. Effect of cutting speed on means of flank wear

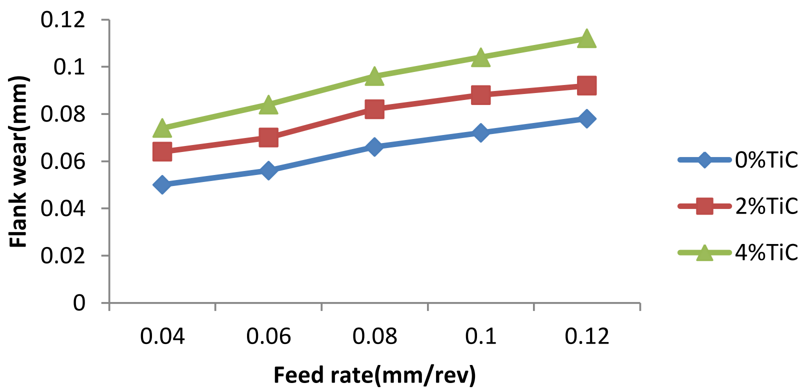

Fig.13. Effect of feed rate on means of flank wear

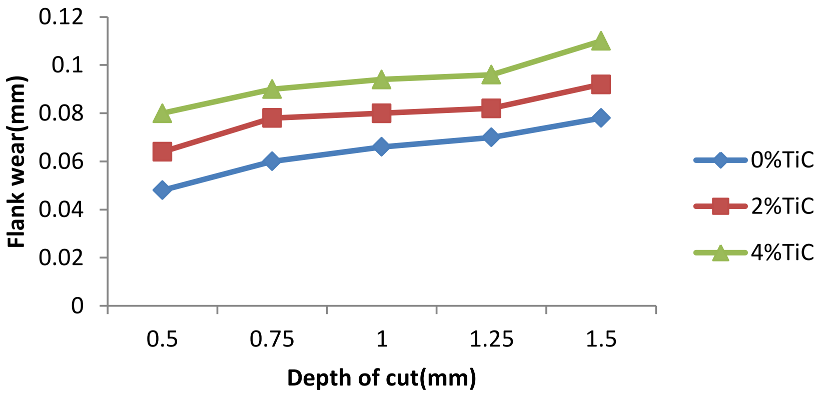

Fig.14. Effect of depth of cut on means of flank wear

temperature of machine interface will increased (2011) which softens the insert edge and raises flank wear, from the Fig.12 it was also observed that the flank wear increases by increase in TiC reinforcement, the increase in TiC reinforcement ratio increases the hardness of the material. Machining harder material results increase in flank wear. Fig. 13 shows the effect of feed rate on means of flank wear, the flank wear increases with the increase in feed rate. The friction between tool and work increases by increase in feed rate and this result an increase in flank wear. Fig.13 also shows that the flank wear increases by increase in harder TiC reinforcement ratio.Fig.14 shows the effect of depth of cut on the means of flank wear, the increase in depth of cut increases the cutting temperature and this softens the tool insert edge which in turn increases flank wear. Fig.14 shows that flank wear increases with the increase in wt% of the TiC reinforcement.

4. Conclusion

In the present research Al6061-2%TiC and Al6061-4%TiC were fabricated by the In-situ process. SEM and EDX test were performed and find the presence of TiC particles. Vickers's micro hardness test was performed and found that the hardness value was increased by increase in wt% of TiC reinforcement. Machinability investigations were performed and found that cutting force was decreased with the increase in the cutting speed. Surface roughness was decreasing by increase in cutting speed. Flank wear was increasing with the increase in cutting speed, this is because higher cutting speed increases cutting temperature and this softens the tool cutting edge. Cutting force was increasing with the increase in feed rate and depth of cut. Surface roughness value was increasing by the increase in feed rate and depth of cut. Flank wear was increasing with the increase in feed rate and depth of cut.

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