BioGecko

Vol 12 Issue 01 2023

ISSN NO: 2230-5807

OPTIMIZATION ON POWDER METALLURGY PROCESS PARAMETERS OF AL7075 BASED COMPOSITES

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Abstract

Alumnium Matrix Nano Composites (AMNCs) are widely utilized for aerospace, automobile, transport and marine applications due to their high ratio of strength to weight, better tribological properties, better mechanical characteristics and corrosion resistance properties. In this research, Al7075 is fortified by the nano Titanium carbide in different percentages of weight. The Al7075/TiC nano composites are manufactured by the powder metallurgy route. The optimization on powder metallurgy parameters of Al7075/xwt.%TiC_{np} (3,6 and 9) composites is done by using Taguchi approach and ANOVA. The chosen powder metallurgy input parameters are sintering time, sintering temperature and wt. % of TiCnp. The chosen parameters for response are micro hardness and wear loss. The L9 orthogonal array is selected for this optimization. The micro hardness and wear test are conducted by utilizing the pin on disc and Vickers tester for hardness. The main effect plot and ANOVA are determined the best combination of powder metallurgy parameters for micro hardness and wear loss responses and are 9 wt.%TiCnp, 60 minutes sintering time and 300 ° C sintering temperature. The highest micro hardness and lowest wear loss are obtained from optimized powder metallurgy parameters.

Key words: Al7075, nano Titanium carbide, Powder metallurgy, TOPSIS, ANOVA.

1. Introduction

The MMCs are needed for wide area applications due to is high wear resistance, corrosion resistance, better specific strength and light weight properties [1-2]. Alumnium is the better matrix metal even though there are much more matrix materials are available [3]. The aluminium metals are very economical, low density and corrosion resistance. Earlier researchers are widely utilized nitride, oxide, boride and carbide based reinforcements for fortifying the matrix metal [4-5]. The ZrO_2, SiC, B_4C, AIN, TiB_2, TiC, Al_2O_3 and TiN are utilized for enhancing the properties of mechanical, corrosion and tribological [6]. The decreasing of particle size increases the strength of the composites. The mechanical characteristics of the macro size particle reinforced composites are not better than the nano size particle reinforced composites [7-8]. The nano sized particles reinforcement decreases the porosity and enhances the bonding strength with matrix material [9]. There are many methods are utilized for manufacturing composites and they are powder metallurgy, centrifugal casting, stir casting, deposition methods, and additive manufacturing [10-11]. The more economical, simplest and better characteristics of powder metallurgy is the reason for using to manufacture the composites than other type of composites [12]. The wide usage of titanium carbide in manufacturing of composite is due to its better mechanical, corrosion and wear resistance characteristics [13]. The Al2024 is fortified by 2 wt. percentage of titanium carbide by using stir casting route. The incorporation of 2wt.% of TiC enhances UTS,YS and hardness to 21%, 54% and 34% respectively. The incorporation of nano particle size TiC by 2.5wt.% reduces the UTS ,YS and hardness [14]. The Al5052 alloy is fortified with TiC by using stir casting setup. The sliding distance, wt.%TiC and applied load are chosen as input process parameters in this investigation. The Fuzzy Logic System (FLS) and Response Surface Methodology are used for investigate the responses [15]. The Al6061 is fortified by TiC by employing stir casting equipment. The incorporation of TiC from 0 to 8 wt.% in step of 2 wt.% into Al6061 matrix material is done to manufacture the composite. The increase of incorporation of TiC enhances the density, strength and hardness of the composites. FLS has better accuracy than RSM [16]. The Al6063 is fortified by TiC using hot extrusion method. The pin on disc setup is employed for finding wear loss. The TiC is fortified by 3 to 9 wt.% in step of 3 wt.%. The incorporation of TiC enhances the resistance for wear in the Al6063/TIC composites [17]. The Al is fortified with TiB2 by using ultra sonic casting approach. The Artificial Neural Network is employed for optimization of process parameters of casting route. The Genetic Algorithm is employed as single objective optimization. The ANN-GA is successfully used for this investigation [18]. The Al is fortified with silicon carbide by employing stir casting setup. The inclusion of silicon carbide enhances the hardness. The influencing of stir casting parameters is determined by using Taguchi approach and ANOVA. The wt.% SiC is the most influential factor on hardness [19]. The AL7075 hybrid composites are manufactured by stir casting setup. The turning parameters optimization for Al7075 based composites is done by TOPSIS method. The cutting speed, depth of cut and feed are taken as input parameters. The tool wear rate and material removal rate are the response parameters. The suitable fabrication method for Al7075 fortification with TiB2 and molybdenum di sulphide is powder metallurgy technique [20]. From the review of the literature, there is no one literature analysed the fabrication and optimization of Al7075/TiC composites on wear loss and micro hardness. In this research, the Al7075 is fortified by titanium carbide in different wt. % (0-9 wt.% in step of 3 wt.%) by using powder metallurgy route and also powder metallurgy parameter optimization is done by employing Taguchi and ANOVA.

2. Materials and Methods

2.1. Materials

The aluminium alloy 7075 material possess not enough wear resistance and mechanical characteristics for using aircraft, automobile, transport and marine applications. These applications are the need of better mechanical properties, high corrosion and wear resistance properties. The aluminium alloy 7075 contains zinc as a dominant element in the chemical composition. The elements presented in the aluminium alloy 7075 are displayed in Table.1. The AA7075 is widely utilized for manufacturing of components like gears, aircraft fitting, shafts, missile parts, worm gears and regulating valve parts. The AA 7075 was purchased from Santhosh metals, Trichy. The purchased AA7075 powder particle average size is 2 μm. The TiC has better mechanical, corrosion and tribological characteristics. The TiC reinforcement was acquired from Sigma Uldrich. The TIC average particle size is 50 nm. The particle size of Al7075 and TiC powder particle is determined by Particle Size Analyzer [21-22]. The details of the Al7075 and TiC powder particles are displayed in Table.2.

Table.1. Chemical composition of Al7075

Elements	Fe	Cr	Mg	Si	Cu	Zn	Mn	Ti	Al
Wt.%	.24	0.20	2.4	0.08	1.5	5.6	0.06	0.07	Bal.

Table.2. Details of Al7075 and TiC powder particles

Property	Al7075	TiC
Tensile Strength	258 MPa	336
Modulus of Elasticity	188 GPa	410
Particle size	2 μm	50 nm
Density	2.81 g/cm^3	4.93 g/cm^3

Poisson ratio	0.3	0.28
Melting Point	560 °C	3160 °C
Purity	99.5	98.5

2.2. Composite fabrication

The matrix Al7075 and reinforcement TiC were used for manufacturing composites in different combination of weight percentages. The Al7075/wt.%TiC composites were manufactured by utilizing Powder metallurgy method. The electronics based weighing measurement machine was utilized for weighing the matrix and reinforcement material. The ball milling was utilized to mix the TiC reinforcement with Al7075 matrix material. The ball milling was done at the condition of 300 rpm rotational speed for 30 minutes. The ball to powder weight ratio used in this fabrication is 5:1. The uni axial hydraulic press with 500 KN capacity was utilized for compacting of composite into the die. The 600MPa compaction pressure was kept constant which was utilized for manufacturing composites [23]. The different particle size of the titanium carbide was employed. The inner wall surface of the die was fully coated by the zinc stearate. The zinc stearate was used to avoid the sticking of matrix and reinforcement in the inner wall of die. The sintering was carried out on the green compacts in the Muffle furnace at different temperature and sintering time. The sintered compacts were cooled in atmospheric condition for 12 hours.

Table.3. L9 with input parameters of powder metallurgy

Trial no	Wt.%TiCnp	Sintering temperature	Sintering time (minutes)
1	3	300	60
2	3	350	120
3	3	400	180
4	6	300	120
5	6	350	180
6	6	400	60
7	9	300	180
8	9	350	60
9	9	400	120

The input parameters chosen for optimization of powder metallurgy parameters are sintering time (60, 120 and 180 minutes), sintering temperature (300, 350 and 400) and wt. % of TiCnp (3, 6 and 9). The chosen responses are wear loss and micro hardness. The L9 orthogonal design of array is utilized for this optimization. The L9 array with their input parameters is displayed in Table.3. The Al7075/TiCnp composites were fabricated as per the combination of input parameters of L9 OA design. The manufactured composites were the diameter of 24 mm and length of 12 mm.

2.3. Testing of Al7075 fortified nano composites

The manufactured Al7075/TiC composites were subjected to wear and micro hardness test for determining the wear resistance and micro hardness. The micro hardness test was conducted as per ASTM E384.The required ASTM size for wear and hardness test was cut from manufactured composite by using Wire cut EDM. The wire cut EDM was utilized for cutting the composites to the required ASTM size. The wire cut EDM is used for cutting without dislocation of particles. The Vickers hardness FMV – 1 model was employed for hardness testing. The three trails were performed for determination of hardness and average value was taken. The pin on disc was utilized for conducting wear test on Al7075/TiCnp composites. The wear test specimen was cut as per ASTM G99. The counter disc was the EN31 material during the wear test. The electronic weighing machine was utilized for weighing the Al7075/TiCnp composites before and after the wear test. The surface of the specimen was maintained at 1µm before conducting wear test. Three trails were done for wear test and average value had been taken. The wear test was conducted at the condition of sliding velocity of 3 m/s, sliding distance of 1600 m and the applied load of 25 N. The wear and hardness test were conducted for all manufactured composites as per L9 orthogonal array.

3. Results and Discussion

The Al7075/TiCnp manufactured composites as per L16 OA were subjected to micro hardness and wear test to determine the micro hardness and wear resistance. The input and response parameters for L9 OA are displayed in Table.4. The Minitab 19 software is employed for optimization. The response table for microhardness is displayed in Table.5. The wt.% TiCnp, sintering temperature and sintering time are the influencing parameter sequence. The Main effect plot for micro hardness is shown in Figure.1. The addition of nano titanium carbide into the Al7075 raises the micro hardness of Al7075 composites. The raising of sintering temperature reduces the micro hardness. The raising of sintering time reduces the micro hardness of the manufactured composites. The increasing of presence of nano titanium carbide in the composites increases the bonding strength between the reinforcement and matrix [24]. The increasing of sintering temperature softens the composites and it causes the decreasing of micro hardness. The increasing of sintering time softens the composites and it causes the decreasing of micro hardness [25].

Factor Information

Factor	**Type**	**Levels**	**Values**
Melting temperature (°C)	Fixed	3	650, 700, 750
Stirring speed(rpm)	Fixed	3	150, 200, 250
Stirring duration (minutes)	Fixed	3	10, 20, 30

Table.4. L9 with input and response parameters of powder metallurgy

Trial no	Wt.%TiCnp	Sintering temperature	Sintering time (minutes)	Micro hardness (HV)	Wear loss (mg)
1	3	300	60	92.0	32.0
2	3	350	120	87.0	34.5
3	3	400	180	83.0	37.5
4	6	300	120	94.0	29.0
5	6	350	180	89.0	31.5
6	6	400	60	91.0	31.0
7	9	300	180	95.0	26.5
8	9	350	60	97.5	25.5
9	9	400	120	93.0	28.0

Table.5.Response Table for Means

Level	**Wt.%TiC**	**Sintering temperature (C)**	**Sintering time (minutes)**

1	87.33	93.67	93.50
2	91.33	91.17	91.33
3	95.17	89.00	89.00
Delta	7.83	4.67	4.50
Rank	1	2	3

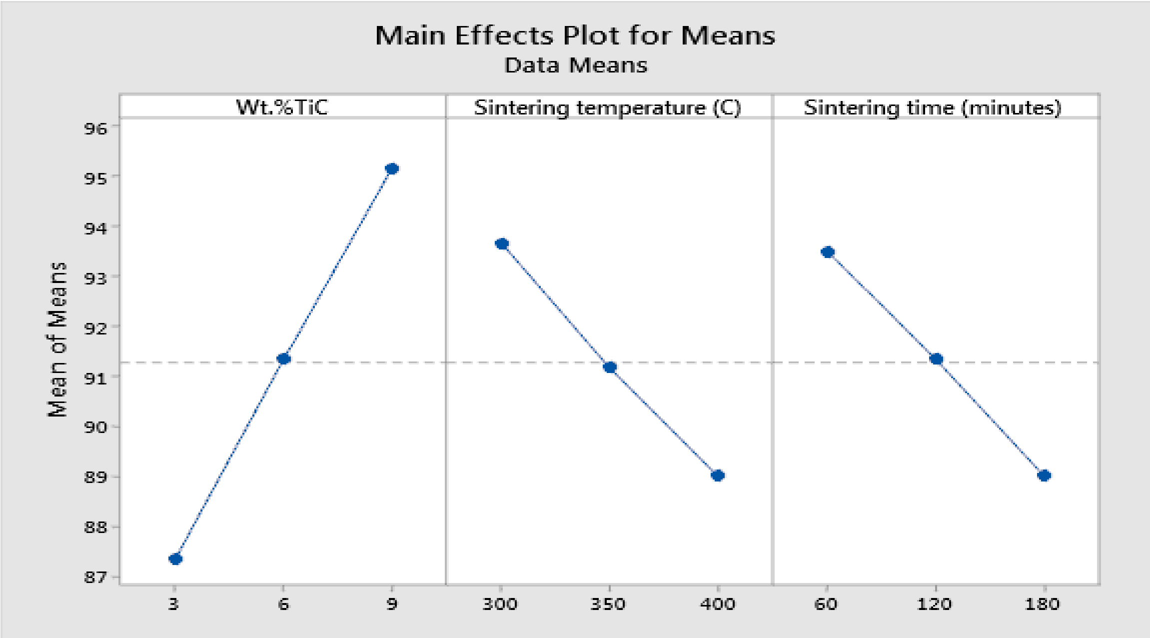

Figure.1. Main effect plot for Means of Micro hardness

Table.6.Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Wt.%TiC	2	92.056	46.0278	236.71	0.004
Sintering temperature (C)	2	32.722	16.3611	84.14	0.012
Sintering time (minutes)	2	30.389	15.1944	78.14	0.013
Error	2	0.389	0.1944		
Total	8	155.556			

Table.7.Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.440959	99.75%	99.00%	94.94%

The ANOVA for micro hardness is displayed in Table.6. The input nano titanium carbide, sintering temperature and time parameters have significant effect on micro hardness because of all p value is less than 0.05. The reliability of the optimization results is high because of adj R square value is 99% and it is shown in Table.7. The better combination of input parameters for micro hardness is observed from main effect plot and ANOVA and it is high level of TiCnP (9wt.%), low level of sintering temperature (300 °C) and low level of sintering time (60 minutes). The contour plots are between micro hardness with wt.%TiC and sintering time, micro hardness with wt.%TiC and sintering temperature and micro hardness with sintering temperature and sintering time and they are shown in

Figure.2.(a-c). From the contour plots, it is observed that wt.% reinforcement is majorly influenced the micro hardness, the increasing of wt.%TiC increases the micro hardness and the increasing of sintering temperature and time decreases the microhardness.The confirmation test is performed at the better combination of input process parameters and the determined micro hardness is 109.

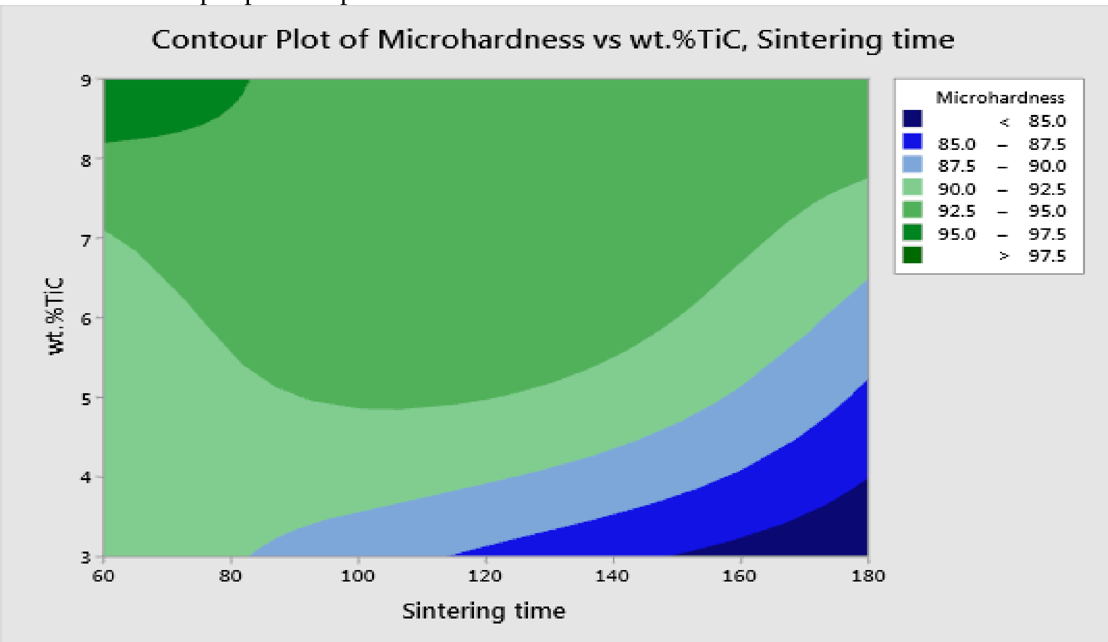

Figure.2.a.Relationship between Micro hardness with wt.%TiC and sintering tiume

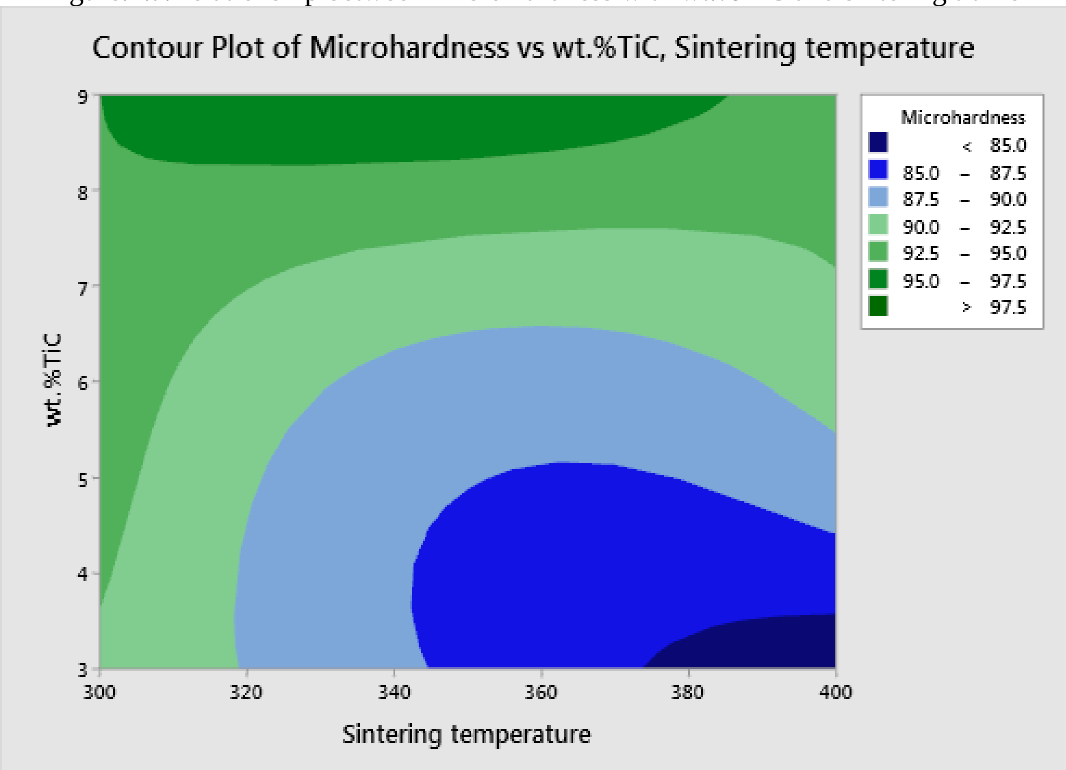

Figure.2.b.Relationship between Micro hardness with wt.%TiC and sintering temperature

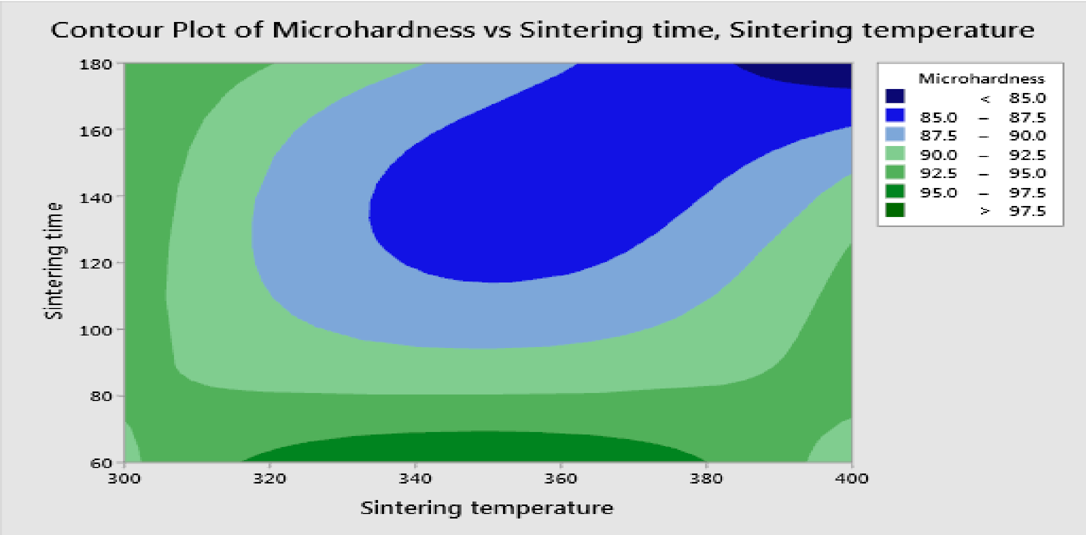

Figure.2.c.Relationship between Micro hardness with sintering time and sintering temperature

Table.8.Response Table for Means

Level	**Wt.%TiC**	**Sintering temperature (C)**	**Sintering time (minutes)**
1	34.50	29.00	29.50
2	30.50	30.50	30.50
3	26.50	32.00	31.50
Delta	8.00	3.00	2.00
Rank	1	2	3

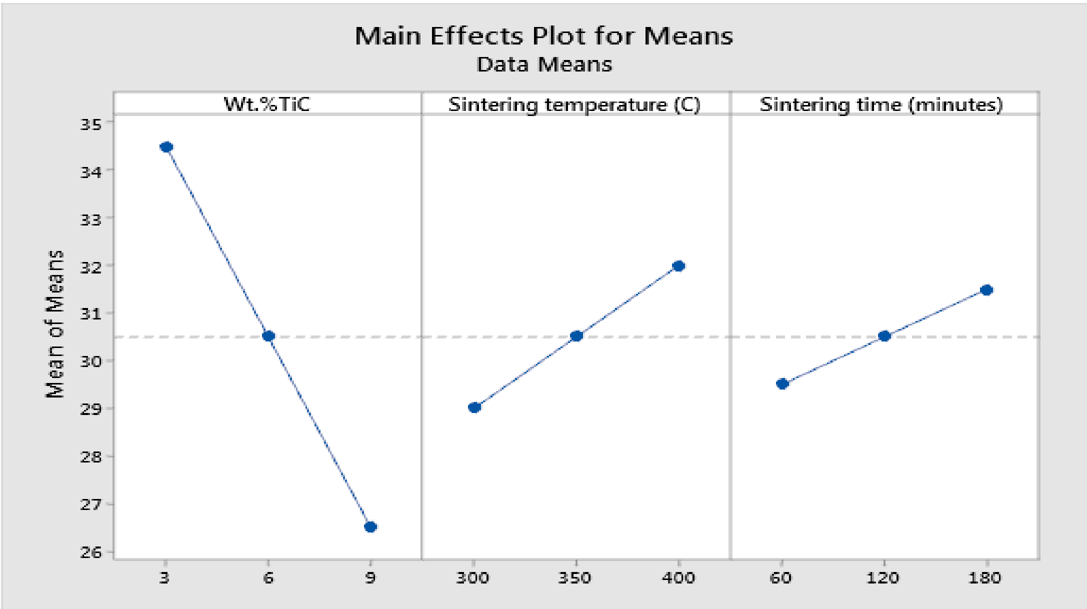

Figure.3. Main effect plot for Wear loss

The response table for wear loss is displayed in Table.8. The wear loss response is influenced by the wt.%TiC , sintering temperature and sintering time respectively. The main effect plot is displayed in Figure.3. The raising of wt.%TiCnp enhances the wear resistance. The increasing of titanium carbide prevents the abrasion of particles. The raising of sintering temperature and time reduces the wear resistance. The raising of sintering temperature and time causes to softening of composites. The wear loss is increased because of soft surface of composites. The β phase is attained while enhancing sintering temperature and sintering time. The ANOVA for wear loss is displayed in Table.9. The all input parameters are significant because of p value of input parameters are smaller than 0.05. The obtained results are in better accuracy because of adj R square value is 99.81% and it is shown in Table.10.The better combination of input parameters for wear loss is high level of TiCnp (9wt.%), low level of sintering temperature (300 °C) and low level of sintering time (60 minutes) and it is obtained from main effect plot and ANOVA.

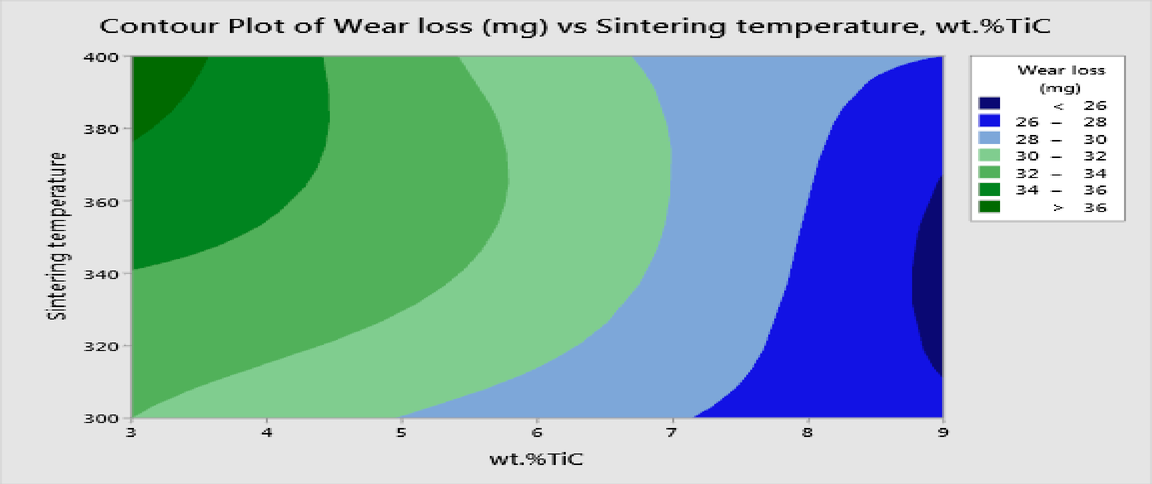

Figure.4.a.Relationship between wear loss with wt.%TiC and sintering temperature

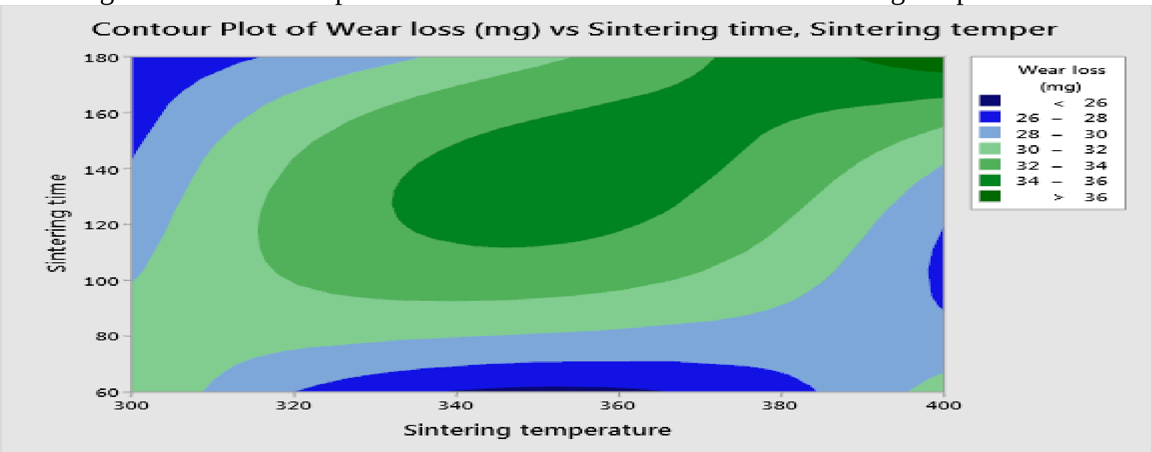

Figure.4.b.Relationship between wear loss with sintering temperature and wt.%TiC

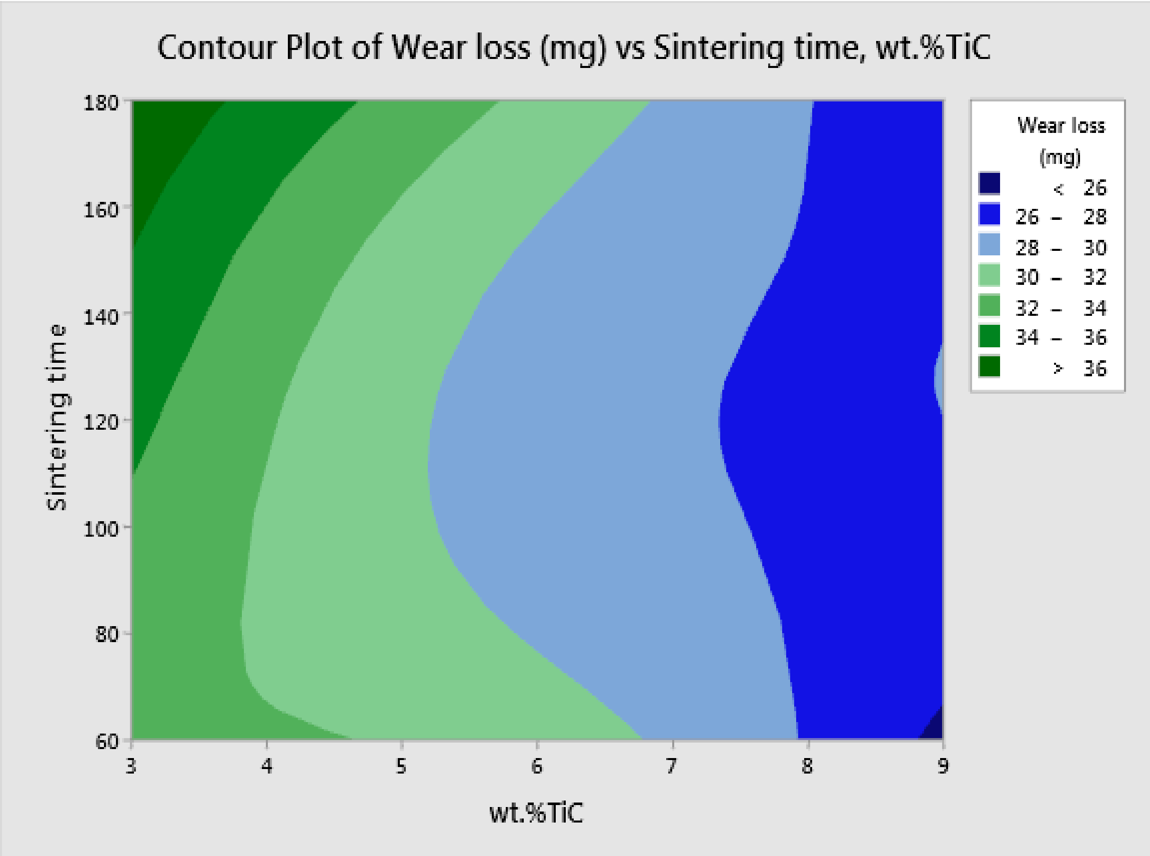

Figure.4.c.Relationship between wear loss with sintering time and wt.%TiC

The contour plots are between wear loss with wt.%TiC and sintering time, micro hardness with wt.%TiC and sintering temperature and wear loss with sintering temperature and sintering time and they are shown in Figure.4.(a-c). From the contour plots, it is observed that wt.% reinforcement is majorly influenced the wear loss, the increasing of wt.%TiC decreases the wear loss and the increasing of sintering temperature and time increases the wear loss .The confirmation test is performed at the better combination of parameters and the obtained wear loss is 16 mg. The micro structure and EDAX test results of Al7075/9wt.% TiCnp is shown in Figure.5. (a-b).The surface of the confirmation test specimen composites is polished with different grit sheets such as 200, 400 , 600 and 800. The surface of the confirmation test specimen is polished to 1 µm. The Figure.3.a shows the micro structure of Al7075/9wt. %TiCnp and it confirms the uniform spreading of TiCnp reinforcements in Al7075 matrix material. The Figure.3.b displays presence of elements.

Table.9.Analysis of Variance

Source	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**
Wt.%TiC	2	96.056	48.0278	1729.00	0.001
Sintering temperature (C)	2	13.556	6.7778	244.00	0.004
Sintering time (minutes)	2	8.222	4.1111	148.00	0.007
Error	2	0.056	0.0278		
Total	8	117.889			

Table.10.Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.166667	99.95%	99.81%	99.05%

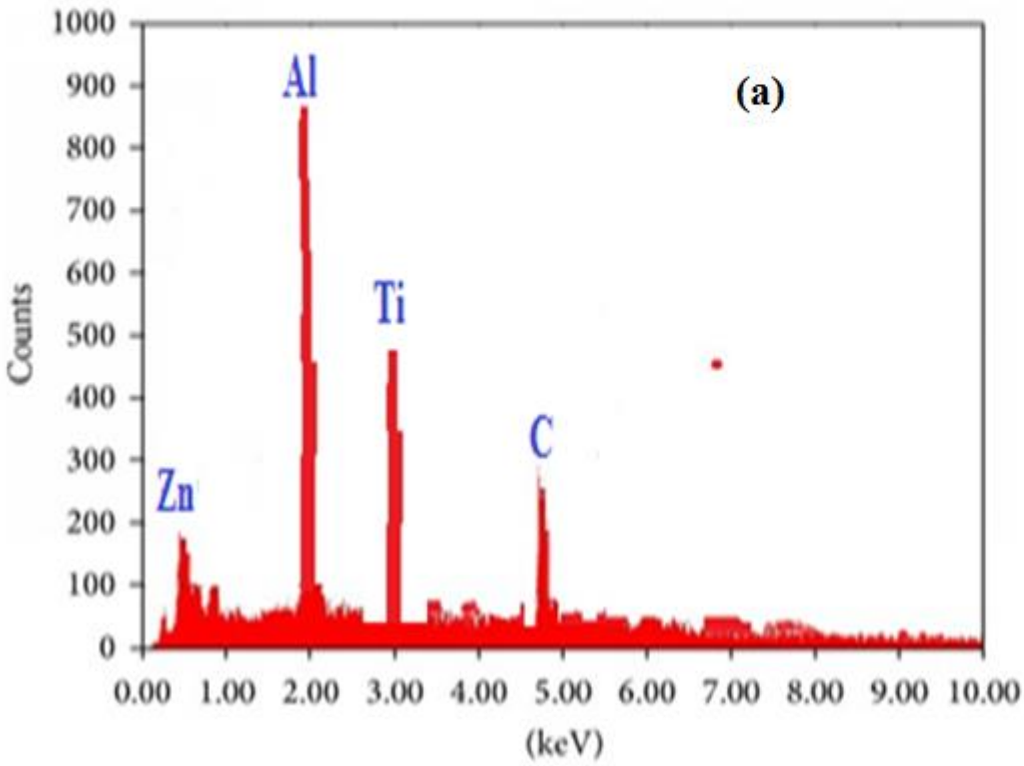

Figure 5.a EDAX of Al7075/9wt.%TiCnp

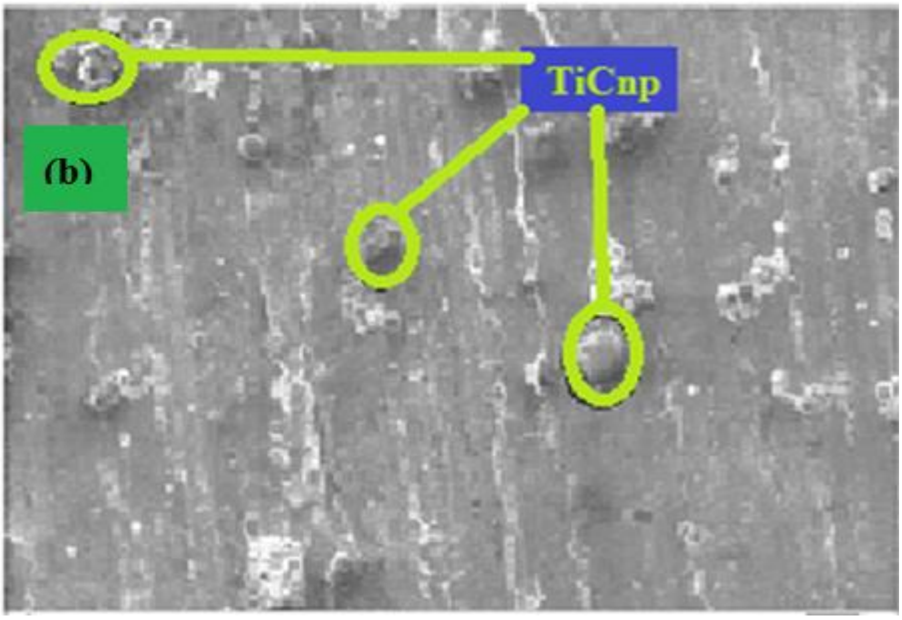

Figure.5.b SEM picture of Al7075/9wt.%TiCnp

4. Conclusions

The aluminium alloy 7075 was reinforced successfully with nano titanium carbide reinforcement in different weight percentages 3.6 and 9 by utilizing the powder metallurgy technique. The compacting pressure 600 MPa was kept constant. The particle size 2µm and 50 nm were employed for aluminium alloy 7075 and TiCnp respectively. The optimization of fabrication parameters of powder metallurgy on Al7075/TiCnp composites is done by the Taguchi and ANOVA method. The input parameters selected for this investigation were wt.%TiCnp, sintering temperature and sintering time. The response parameters selected for this investigation were micro hardness and wear loss. The better combination of input parameters for micro hardness was observed from main effect plot and ANOVA and it was high level of TiCnP (9wt.%), low level of sintering temperature (300 °C) and low level of sintering time (60 minutes). The confirmation test was performed at the better combination of input process parameters and the determined micro hardness was 109. The better combination of input parameters for wear loss was high level of TiCnP (9wt.%), low level of sintering temperature (300 °C) and low level of sintering time (60 minutes) and it was obtained from main effect plot and ANOVA. The confirmation test was performed at the better combination of parameters and the obtained wear loss was 16 mg. The SEM picture of Al7075/9wt.%TiCnp confirmed the uniform distribution of reinforcement.

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