

mechanics

\$ sciendo

# The influence of carbide reinforcement on the properties of sintered aluminium alloy matrix composites

#### Aneta Szewczyk-Nykiel

Scientific Editor: Jacek Pietraszek, Cracow University of Technology Technical Editor: Aleksandra Urzędowska, Cracow University of Technology Press Language Verification: Timothy Churcher, Merlin Language Services Typesetting: Małgorzata Murat-Drożyńska, Cracow University of Technology Press

Received: January 26, 2023 Accepted: April 11, 2023

**Copyright:** © 2023 Szewczyk-Nykiel. This is an open access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.

**Data Availability Statement:** All relevant data are within the paper and its Supporting Information files.

**Competing interests:** The authors have declared that no competing interests exist.

**Citation:** Szewczyk-Nykiel,A. (2023). The influence of carbide reinforcement on the properties of sintered aluminium alloy matrix composites. *Technical Transactions, e2023005.* https://doi.org/10.37705/ TechTrans/e2023005

#### Abstract

Based on the commercial aluminium alloy powder blend (Alumix 431D) metal matrix composites reinforced with particles of SiC as well as TiC were produced by conventional powder metallurgy technology and the effect of the type and amounts of reinforced particles on the selected properties and microstructure of sintered composites were investigated. In particular, the densification behaviour, the wear resistance and the corrosion resistance in 3.5% NaCl solution were identified. It was stated that both the type and the weight fraction of carbide used as particulate reinforcement have a great impact on the properties of aluminium alloy matrix composites. It was shown that the introduction of titanium carbide has a more favourable effect on the properties of sintered Alumix 431D matrix composite is 4 wt. % due to the highest hardness, wear resistance (wear rate of 2.865·10<sup>-3</sup> mm<sup>3</sup>/m) and simultaneously the best corrosion resistance (corrosion rate of 0.005 mm/year).

Keywords: aluminium alloy matrix composites, Alumix 431D, SiC, TiC, density, hardness, wear resistance, corrosion resistance, microstructure

# No. 2023/005

## 1. Introduction

Aluminium matrix composites (AMCs) have found wide-spread use in various engineering applications, especially in the automotive and aerospace industries (Gasali et al., 2017), due to their attractive properties, such as low density, high strength-to-density and stiffness-to-density ratio, toughness, corrosion resistance, improved wear resistance, increased creep resistance, low coefficient of thermal expansion, and improved elevated temperature properties (Penchal et al., 2016).

Many processing techniques have been used to fabricate AMCs, namely powder metallurgy (Vani et al., 2018), casting routes (Mohanavel et al., 2018), mechanical alloying (Kaftelen et al., 2011) and in-situ synthesis (Rai et al., 2016). The main problems of casting are reinforcement segregation, unwanted interfacial chemical reactions, porosity, and poor interfacial bonding. However, powder metallurgy technology offers lower processing temperature, lower energy consumption, higher raw material savings, fabrication of parts that are net shaped or near net shaped, and of course, almost uniform distribution of reinforcement particles compared to the casting method (Dudhmande et al., 2005).

Aluminium matrix composites are usually reinforced with particles of ceramic materials. Silicon carbide is a commonly used reinforcement in AMCs due to its physical and chemical compatibility with the matrix, its high hardness and modulus of elasticity and due to it having the highest thermal conductivity off all structural ceramics (Roy et al., 1992).

Studies relating to the fabrication of sintered SiC-reinforced aluminium matrix composites (with varying particle sizes and mass fractions of reinforcement), the investigation of their properties and microstructure characterisation can be found in the literature (Hemalathaa et al., 2022; Reddy et al., 2020; Patel et al., 2020; Aatthisugan et al., 2020; Mahesh et al., 2017). Several researchers have noticed that an increase in SiC reinforcement content results in an increase in tensile strength, hardness and wear resistance, while it causes a decrease in the ductility of aluminium matrix composites (Roy et al., 1992; Leszczyńska-Madej, 2013). For example, the sliding wear behaviour of the sintered SiC-reinforced aluminium matrix composites has been studied using a pin-on-disc method (an applied load of 80N and 160N and a sliding velocity of 1m/s) (Roy et al., 1992). Distinctly lower wear rates were reported in composites in comparison to pure aluminium. The results indicate that the wear rate decreased with increasing volume fractions of the reinforcing particulate up to 20% vol. A compacted at 400 MPa and sintered at 630°C under vacuum 6711Al (Al-1Mg-0.8Si-0.25Cu) - SiC composites were investigated (Leszczyńska-Madej, 2013). This was found that composites reinforced with SiC up to 10% vol. exhibited better densification, yield strength, wear and corrosion resistance due to uniform distribution of SiC particles throughout the matrix. Higher volume fractions of SiC had an unfavourable effect on the densification and mechanical properties of composites because of the agglomeration of SiC particles at the grain boundaries of the matrix; however, it caused significant improvement in hardness and wear resistance as a result of the abrasive nature of SiC particles.

Only a very few works have been published that relate to the use of Alumix 431D as a matrix in ceramic particle-reinforced composites (Rudianto et al., 2015; Lee et al., 2017; Izadi et al., 2013). Alumix 431D is an Al-Zn-Mg alloy (7xxx series) and exhibits high sinterability, providing near-full density and high-strength sintered material. It should be noted that the parameters of the sintering process have an important influence on the densification of Alumix 431D. For example, it was stated that nitrogen is the most suitable atmosphere because it is able to increase diffusivity during sintering by liquid phase formation. Previous research has revealed that the optimal sintering temperature of Alumix 431D is 590°C due to the highest relative density (Pieczonka et al., 2012).

Some researchers investigated SiC-reinforced Alumix 431D matrix composites fabricated by powder metallurgy using conventional pressing (Rudianto et al., 2015), hot-pressing process (Lee et al., 2017) or friction stir



processing (Izadi et al., 2013). According to research Rudianto et al., 2015), sintered Alumix 431D – 13 vol% SiC composite shows a good combination of mechanical properties and wear resistance. A relative density of 96% was obtained for this composite due to the enhanced sintering process.

According to research studies, titanium carbide is known to exhibit high hardness, high elastic modulus, high thermal conductivity, a high melting point, good wetting, chemical inertness and low density (Mahesh et al., 2017). Such properties make titanium carbide a suitable reinforcement for metal matrix composites.

To the best of the author's knowledge, no reports have yet been made on the effect of titanium carbide on the properties and microstructure of sintered Alumix 431D matrix composites.

In this study, aluminium alloy matrix composites reinforced with SiC and TiC particles were produced by conventional powder metallurgy technology. They were prepared from Alumix 431D mixed with carbides at the amount of 2 and 4 wt.%. The primary aim of this work was to determine the effect of the chemical composition on the selected properties and evaluation of the microstructure of sintered carbide-reinforced Alumix 431D matrix composites.

#### 2. Experimental procedure

In the present studies, a commercial powder blend designated as Alumix 431D (produced by ECKA Granules) was used. Alumix 431D is a mixture of air-atomised pure aluminium powder with a master alloy containing Al, Zn, Mg and Cu. The chemical composition of Alumix 431D was shown in Table 1. The physical characteristics of the powder: apparent density of 1.35 g/cm<sup>3</sup>, flow (50 g/2.54 mm) < 30 s., particle size: 100% < 200 $\mu$ m, 30% < 45 $\mu$ m. Alumix 431D is similar to that of wrought 7075 aluminium alloy. It is worth mentioning that the investigated powder contains the of lubricant in the form of Acrawax C at a quantity of 1.5 wt.%. Silicon carbide (a purity of 99.8%, an average particle size of 20  $\mu$ m) and titanium carbide (a purity of 99.5%, an average particle size of 10  $\mu$ m) were used as the particulate reinforcement.

Table 1. Chemical composition of Alumix 431D powder (wi	.%)	
---	-----	--

Zn	Mg	Cu	Sn	Al
5.8	2.9	1.80	0.18	bal.

The following powder mixtures were prepared:

- Alumix 431D 2 wt.% SiC,
- ► Alumix 431D 4 wt.% SiC,
- Alumix 431D 2 wt.% TiC,
- Alumix 431D 4 wt.% TiC.

In order to compare the results, pure Alumix 431D powder was also used in these studies.

The powder mixtures containing Alumix 431D and appropriate carbide were prepared by mixing in Turbula®mixer for 4 hours. The powder mixtures and Alumix powders were then uniaxially pressed in a rigid matrix at 580 MPa into cylindrical samples of size Æ20´5 [mm] and Æ25.4´6 [mm]. The sintering process was performed in a Nabertherm furnace. All green compacts were sintered in a nitrogen atmosphere. The samples were heated to the temperature of 590°C at a rate of 10°C/min, held at an isothermal sintering temperature for 60 mins, and then cooled to ambient temperature at a rate of 10°C/min. During heating, the samples were delubricated at a temperature of 410°C for 30 mins under flowing nitrogen. The heating and cooling rates were 10 C/min.

The density measurements of green compacts were performed by the geometrical method. The density and porosity of the sintered samples were measured by the water-displacement method (according to the demands of the

PN-EN ISO 2738:2001 norm). The rule of mixture was used to determine the theoretical density of the sintered composites.

The hardness measurements by the Rockwell method (B scale) were conducted according to the PN-EN ISO 4498:2010 norm.

Microstructural observation of the sintered metal matrix composites was performed using a JSM 5510LV scanning electron microscope.

A Mitutoyo Surf Test SJ-301 surface roughness tester was used to perform roughness measurements. The surface roughness parameters (*Ra*, *Rz*, *Rq*) were determined.

In accordance with the ASTM G99-95A: 'Standard Test Method for Wear Testing with Pin-on-Disk Apparatus', dry sliding wear tests were performed using a ITeE-PIB T-01M tribotester. A ball made of 1.3505 steel with a hardness of 40 HRC was used as a counter-sample. The applied load of 10 N and sliding velocities of 0.1 m/s and 0.2 m/s were used. The sliding distance was 500 m. The coefficient of friction as a function of the sliding distance was recorded. The coefficient of friction, the absolute mass loss and the wear rate were defined in order to evaluate the wear resistance of the studied materials under conditions of dry sliding friction.

The corrosion resistance study included the open-circuit potential measurement and potentiodynamic polarisation technique. They were performed using the ATLAS 0531 (electrochemical unit & impedance analyser controlled by AtlasCorr05 software) in an environment of 3.5% NaCl solution at ambient temperature. A conventional three-electrode system including the working electrode (the sample of the studied material) the counter electrode (platinum electrode) and the reference electrode (saturated calomel electrode) was used. The variation of OCP with the immersion time (30 minutes) was recorded. The potentiodynamic polarisation experiment was then performed at a potential scan rate of 1.0 mV/s from -1.2 V to -0.5 V. The polarisation resistance ( $R_{pol}$ ), the corrosion current density ( $i_{corr}$ ), corrosion potential ( $E_{corr}$ ), cathodic ( $b_c$ ) and anodic ( $b_a$ ) Tafel constants were determined.  $R_{pol}$  was evaluated using the Stern method as well as the Stern-Geary method. The corrosion rates including both the penetration rate (*CR*) and the mass loss rate (*MR*) were determined according to the standard ASTM G 102.

## 3. Results and discussion

The microstructure studies of sintered Alumix 431D are presented in the literature (Pieczonka et al., 2012). The microstructures of the sintered Alumix 431D matrix composites reinforced with carbide particles are shown in Figures 1-4. A near-homogeneous distribution of TiC as well as SiC particles were observed in the matrix material. However, in the case of higher reinforcement content, there was a slight agglomeration of ceramic particles in the matrix and the formation of a porous structure occurred in the areas adjacent to these particles in the microstructure of the composites studied.

Figures 5a) and 5b) show the effect of the SiC and TiC content on the green and sintered density of the Alumix 431D and Alumix 431D matrix composites, respectively. These figures also show the values of theoretical density for the sintered Alumix 431D matrix composites with different weight percentages of carbides.

Significant densification of Alumix 431D compacts occurred during the sintering process and a relative density of almost 99% was achieved. This is due to the improved sintering activity of this material (a predominant supersolidus sintering) (Dudhmande et al., 2005; Rudianto et al., 2015; Pieczonka et al., 2012). It is visible that the presence of carbides as particulate reinforcement caused an increase in the density of composites after the pressing process in comparison to that of the matrix material. The increase in density is attributed to the higher density of SiC as well as TiC compared to Alumix 431D. The sintered





Fig. 1. The microstructure (SEM) of sintered Alumix 431D - 2 wt.% SiC composite
Fig. 2. The microstructure (SEM) of sintered Alumix 431D - 2 wt.% TiC composite

Fig. 3. The microstructure (SEM) of sintered Alumix 431D – 4 wt.% SiC composite
Fig. 4. The microstructure (SEM) of sintered Alumix 431D – 4 wt.% TiC composite

Fig. 5. Green density, theoretical and experimental sintered density: a) Alumix 431D – SiC composites, b) Alumix 431D – TiC composites



Alumix 431D matrix composites reinforced with SiC particles exhibited almost the same density values as an unreinforced aluminium alloy. The addition of TiC to Alumix 431D of up to 4 wt.% caused a slight increase in density after the sintering process. In the case of the studied composites, the theoretical and experimental sintered density values were slightly different from each other, and the relative density decreased to 98% with increasing carbide content. The effect of the presence of SiC particles in the Alumix 431D matrix on the deterioration of sinterability was also observed in previous articles (Dudhmande et al., 2005; Rudianto et al., 2015; Rudianto et al., 2015).



A distinct influence of the reinforcement particles on the porosity of composites studied can also be observed. The results of open and closed porosity measurements for the sintered Alumix 431D matrix composites reinforced with TiC and SiC particles are presented in Figures 6a) and 6b), respectively. The open porosity was found to increase significantly, while the closed porosity decreased with the increase in carbide content of up to 4 wt.% in the composites. Ultimately, the total porosity increased slightly. Furthermore, the Alumix 431D – SiC composites exhibited slightly higher open porosity and lower closed porosity compared to the Alumix 431D – TiC composites.

The results of the HRB hardness measurements of the studied materials are presented in Figure 7. In accordance with to expectations, the presence of carbide-reinforcing particles in the aluminium alloy matrix resulted in an increase in the hardness of the composites studied. This is related to the higher hardness of SiC as well as TiC compared to Alumix 431D. It is known that the introduction

# ■∷technical ■□ transactions



of reinforcement particles with higher

hardness to a matrix material with

lower hardness ensures a higher

hardness of the composite. An

increase in the carbide content of up to 4 wt.% resulted in a maximum HRB



**Fig. 6.** Open and closed porosity: a) Alumix 431D – SiC composites, b) Alumix 431D – TiC composites



431D – SiC. This is explained by the higher hardness of the titanium carbide.

b)

1.2

1,0

∑<sub>0,8</sub>

open porosity

■ closed porosity

The results of the roughness measurements of the surface of the studied samples are presented in Table 2. It was found that the presence of carbidereinforcing particles in the aluminium alloy matrix resulted in a marked increase in surface roughness. Regardless of the type of carbide used as reinforcement, the values of all measured surface roughness parameters slightly decreased with increasing amounts of carbide particles in the studied composites. The use of titanium carbide seems to be more advantageous because of the lower values of the roughness parameters.

Chemical composition	Rα <b>[μm]</b>	Rz [µm]	Rq [µm]	
Alumix 431D	0.72 ± 0.03	5.07 ± 0.35	0.93 ± 0.05	
Alumix 431D – 2% TiC	3.57 ± 0.07	21.95 ± 0.80	4.49 ± 0.16	
Alumix 431D – 4% TiC	3.05 ± 0.12	20.58 ± 0.32	4.08 ± 0.12	
Alumix 431D – 2% SiC	3.59 ± 0.10	22.01 ± 0.78	4.53 ± 0.18	
Alumix 431D – 4% SiC	3.28 ± 0.11	20.37 ± 0.73	4.09 ± 0.13	

 Table 2. The average values of the surface roughness parameters for sintered Alumix 431D and
 Alumix 431D matrix composites reinforced with carbide particles

The recorded dependences of the coefficient of friction on the sliding distance for the sliding velocity of 0.1 m/s are presented in Figures 5a) and 5b) for sintered Alumix 431D matrix composites reinforced with TiC and SiC particles, respectively.

In the case of all studied materials, it was observed that in the initial stage of the test, the coefficient of friction rapidly increased, reaching the maximum value due to the running-in process of the surfaces between the ball and the disk. The coefficient of friction then decreased slightly and stabilised. This corresponds to a sliding distance of approximately 90–100 m for the sliding velocity of 0.1 m/s and 50–60 m for the sliding velocity of 0.2 m/s.

The average values of the coefficient of friction, as well as the values of the absolute mass loss and wear rate of materials studied obtained during the wear-resistance test at sliding velocities of 0.1 m/s and 0.2 m/s are presented in Table 3.

Fig. 7. The effect on carbide content on HRB hardness of sintered Alumix 431D – SiC and Alumix 431D – TiC composites



**Fig. 8.** Dependence of the coefficient of friction on the sliding distance during dry sliding friction (applied load of 10N, sliding velocity of 0.1 m/s) for sintered Alumix 431D and: a) Alumix 431D – TiC composites, b) Alumix 431D – SiC composites

 Table 3. The average value of the coefficient of friction, wear rate and absolute mass loss of sintered
 Alumix 431D and Alumix 431D matrix composites reinforced with carbide particles

Chemical composition	μ [-]		Δm [g]		wear rate [10 <sup>-3</sup> mm³/m]	
	0.1 m/s	0.2 m/s	0.1 m/s	0.2 m/s	0.1 m/s	0.2 m/s
Alumix 431D	0.48 ± 0.01	0.50 ± 0.02	0.015	0.018	10.858	13.029
Alumix 431D – 2% TiC	0.31 ± 0.02	0.41 ± 0.02	0.007	0.009	5.047	6.489
Alumix 431D – 4% TiC	0.22 ± 0.02	0.33 ± 0.01	0.004	0.008	2.865	5.731
Alumix 431D – 2% SiC	0.38 ± 0.02	0.46 ± 0.02	0.009	0.012	6.510	8.680
Alumix 431D – 4% SiC	0.37 ± 0.02	0.43 ± 0.01	0.006	0.010	4.337	7.228

It was observed that regardless of the sliding velocity, the absolute mass loss of the sample and the wear rate of all investigated composites were significantly lower than those of the aluminium alloy. Furthermore, the increase in carbide content by up to 4 wt.% in the composition of the composite contributed to the decrease in the values of the friction coefficient, the absolute mass loss and the wear rate. For all studied materials, the friction coefficient as well as the wear rate and the loss of mass of the sample was also observed to have obtained higher values at a sliding velocity of 0.2 m/s. Regardless of the sliding velocity, Alumix 431D - TiC composites exhibited better wear resistance compared to Alumix 431D - SiC. This was confirmed by lower values of the absolute mass loss, the wear rate, and the coefficient of friction for the Alumix 431D – TiC composites. It can be stated that the introduction of titanium carbide has a favourable effect on the wear resistance of the Alumix 431D matrix composites. An increase in the wear resistance of composite due to the incorporation of hard ceramic reinforcements in the Alumix 431D matrix was also confirmed in articles [7, 8, 18]. For example, it was found that the Alumix 431D – 13% SiC composite exhibited low disk wear as well as low counterpart attack and the friction coefficient varied between 0.10-0.35 (depending on the load and rotation speed) (Dudhmande et al., 2005).

The open circuit potential is known as a parameter for determining the thermodynamic tendency of a material to electrochemical corrosion reactions in a corrosive environment. Figures 9a) and 9b) present the variation of the open circuit potential over time (an environment of 3.5% NaCl solution) for the investigated materials. In the case of all investigated materials, a shift of the OCP in the direction of positive values over time can be observed as a result of the formation of a passive layer on the surface of the sample. The OCPs at the beginning and end of the test reached the lowest and highest values, respectively. The studied composites exhibited higher values of OCP in comparison to the aluminium alloy.

The potentiodynamic polarisation curves of the sintered Alumix 431D and Alumix 431D matrix composites reinforced with SiC and TiC are shown in Figures 10a) and 10b), respectively. The values of the following electrochemical

# ■∷technical ■□ transactions



Fig. 9. The variation of OCP with time for sintered Alumix 431D and: a) Alumix 431D – TiC composites, b) Alumix 431D – SiC composites

Fig. 10. Potentiodynamic polarisation curves of sintered Alumix 431D and: a) Alumix 431D – TiC composites, b) Alumix 431D – SiC composites

parameters of the investigated materials are presented in Table 4: polarisation resistance  $(R_{pol})$ ; corrosion potential  $(E_{corr})$ ; corrosion current density  $(i_{corr})$ ; cathodic  $(b_c)$  and anodic  $(b_a)$  Tafel constants; and corrosion rate (*CR* and *MR*).

Based on the analysis of the results presented above, it can be concluded that the increase in the amount of TiC in the Alumix 431D matrix composites has a beneficial influence on corrosion resistance because it led to lower values of the corrosion current density, corrosion rate and an increase in polarisation resistance. It can be stated that the sintered Alumix 431D - 4 wt.% TiC exhibited the highest corrosion resistance in the 3.5% NaCl solution. This was clearly confirmed by the highest polarisation resistance and simultaneously the lowest corrosion current density.

The influence of SiC on the corrosion resistance of the Alumix 431D matrix composite is not as clear. It was observed that the polarisation resistance increased with the increase in the amount of SiC up to 2 wt.%; it then decreased to the value lower than for sintered Alumix 431D. The lowest polarisation resistance and simultaneously the highest values of the corrosion current density and the corrosion rate were achieved by the Alumix 431D – 4 wt.% SiC composite. This material exhibited the lowest corrosion resistance in the 3.5% NaCl solution.

 Table 4. The values of polarisation resistance, corrosion potential, corrosion current density, cathodic and anodic Tafel constants, and corrosion rate of the sintered Alumix 431D and Alumix 431D matrix composites reinforced with carbide particles

	Alumix 431D	Alumix 431D – 2% SiC	Alumix 431D – 4% SiC	Alumix 431D – 2% TiC	Alumix 431D – 4% TiC
$R_{pol} \left[\Omega \ \mathrm{cm^2} ight]^{\mathrm{(1)}}$	18315	23529	9588	42373	94340
$R_{pol} \left[ \Omega \ { m cm}^2  ight]  {}^{_2)}$	35912	37579	14049	59448	113793
E <sub>corr</sub> [V]	-1.008	-1.075	-1.049	-0.988	-0.971
i <sub>corr</sub> [A/ cm <sup>2</sup> ]	7.99E-07	6.40E-07	2.26E-06	6.96E-07	4.55E-07
$b_c [V]$	0.163	0.085	0.125	0.125	0.167
$b_a$ [V]	0.111	0.159	0.176	0.400	0.420
CR [mm/year]	0.009	0.007	0.026	0.008	0.005
MR [g/m²d]	0.071	0.057	0.200	0.062	0.040
<sup>1)</sup> Stern method <sup>2)</sup> Stern-Geary method					

Some investigators have reported an improvement in the corrosion resistance of aluminium alloy matrix composites due to the addition of ceramic particles (Sambathkumar et al., 2016; Bobic et al., 2010; Murthy et al., 2015; Verma et al., 2015; Zakaria, 2014). The corrosion rate of aluminium alloy matrix composites depends on several parameters, including, among others, the composition of components, processing techniques, the state of the surface, and the environment. The experimental results indicated that the composites may exhibit completely different corrosion behaviour due to a variety of aluminium alloys and reinforcement types. According to the literature (Loto, 2018), increasing the content of SiC and the size of SiC particles increased the appearance of localised corrosion in a chloride solution and decreased the corrosion resistance of 1070AL-SiC cast composites. On the other hand, the immersion test in a solution of 3.5% NaCl revealed that the corrosion resistance of sintered Al-SiC composites increased with increases volume fraction of the SiC of up to 15% and a reduced SiC particles size (Zakaria, 2014). While Hybrid Al7075 – TiC – SiC composites (prepared by the two-step stir casting route) a exhibited better corrosion resistance in 3.5 wt.% NaCl solution as compared to the matrix material. It was also found that increasing the volume fraction of reinforcement particulates from 0 to 15 vol.% increased the corrosion resistance of these composites (Sambathkumar et al., 2016). According to some authors, pitting attack is the main form of corrosion in composites and a preferential pitting attack occurs at the matrix/reinforcement interface due to poor bonding between them, the presence of pores and the presence of cracked reinforcement particles (Sambathkumar et al., 2016; Bobic et al., 2010; Murthy et al., 2015; Verma et al., 2015).

## 4. Conclusions

Based on commercially available grades of carbides and aluminium alloy powders, carbide-reinforced Alumix 431D matrix composites were manufactured using conventional powder metallurgy technology and were then investigated. It was confirmed that both the type and weight fraction of carbides used as reinforcement have a significant impact on the properties of aluminium alloy matrix composites. The sintered Alumix 431D - TiC composites were shown to have higher hardness as well as better wear resistance and corrosion resistance in the 3.5% NaCl solution compared to the Alumix 431D - SiC composites. It was clearly confirmed by lower values of the absolute mass loss, the wear rate, and the coefficient of friction as well as the higher polarisation resistance and simultaneously the lower corrosion current density for Alumix 431D - TiC composites. Regardless of the type of particulate reinforcement, the increase of carbide content of up to 4 wt.% in composition of composite contributed to improvement of hardness and wear resistance. It was shown that sintered Alumix 431D – 4 wt.% TiC reaches the highest hardness, wear resistance (wear rate of 2.865×10<sup>-3</sup> mm<sup>3</sup>/m) and simultaneously the highest corrosion resistance in 3.5% NaCl solution (a corrosion rate of 0.005 mm/year). It can be stated that the introduction of titanium carbide has a favourable effect on the properties of sintered Alumix 431D matrix composites.

- Aatthisugan, I. et al. (2020). Effect of Sintering Temperature on Microstructure and Mechanical Properties of Aluminium Composites, *IOP Conference Series: Materials Science and Engineering*, https://doi.org/10.1088/1757-899X/912/3/032070.
- Bobic, B., Mitrovic, S., Babic, M., Bobic, I. (2010). Corrosion of Metal-Matrix Composites with Aluminium Alloy Substrate, *Tribology in Industry*, 32, 3–11.
- Dudhmande, A., Schubert, Th., Balasubramanian, M., Kieback, B. (2005). Sintering and Properties of New P/M Aluminium Alloys and Composites, *Powder Metallurgy World Congress & Exhibition, Euro PM 2005.* Prague.
- Ghasali, E., Fazili, A., Alizadeh, M., Shirvanimoghaddam, K., Ebadzadeh, T. (2017). Evaluation of Microstructure and Mechanical Properties of Al-TiC Metal Matrix Composite Prepared by Conventional, Microwave and Spark Plasma Sintering Methods, *Materials*, 10, 1255, https://doi.org/10.3390/ ma10111255
- Hemalathaa, A., Udhayakumar, P. (2022). Experimental Investigation on Influence of Process Parameters on Properties of Powder Synthesized Aluminium Metal Matrix Composites by Taguchi's Analysis, *Materials Research*, 2022, 25(6), https://doi.org/10.1590/1980-5373-MR-2022-0083
- Izadi, H., Nolting, A., Munro, C., Bishop, D.P., Plucknett, K.P., Gerlich, A.P. (2013) Friction stir processing of Al/SiC composites fabricated by powder metallurgy, *Journal of Materials Processing Technology*, 213, 1900–1907, https://doi.org/10.1016/j.jmatprotec.2013.05.012.
- Kaftelen, H., Ünlü, N., Göller, G., Öveçoglu, M., Henein, H. (2011). Comparative processing-structure-property studies of Al-Cu matrix composites reinforced with TiC particulates, *Composites Part A: Applied Science and Manufacturing*, 42, 812–824, https://doi.org/10.1016/j. compositesa.2011.03.016.
- Lee, E., Oak, J.J., Kim, Y., Park, Y. (2017). Effect of Added Gas-Atomized Al-Si/SiCp Composite Powder on the Sinterability and Mechanical Properties of Alumix 431 fabricated by Hot-Pressing Process, *Korean Journal of Metals and Materials*, 55(2), 98–109, https://doi.org/10.3365/KJMM.2017.55.2.98
- Leszczyńska-Madej, B. (2013). The effect of sintering temperature on microstructure and properties of Al-SiC composites, *Archives of Metallurgy and Materials*, 58(1), 43–48, https://doi.org/10.2478/v10172-012-0148-7
- Loto, R.T. (2018). Investigation of the influence of SiC content and particle size variation on the corrosion resistance of Al-SiC matrix composite in neutral chloride solution, *The International Journal of Advanced Manufacturing Technology*, https://doi.org/10.1007/s00170-018-3137-9
- Mahesh, L., Sudheer Reddy, J., Mukunda, P.G. (2017). Compaction, Sintering and Characterization of TiC Reinforced Aluminum Metal Matrix Composites, *SSRG International Journal of Mechanical Engineering*, 4(2), 23–27, https:// doi.org/10.14445/23488360/IJME-V4I2P104
- Matli, P.R., Shakoor, R.A., Mohamed, A.M.A., Gupta, M. (2016). Microwave Rapid Sintering of Al-Metal Matrix Composites: A Review on the Effect of Reinforcements, Microstructure and Mechanical Properties, *Metals*, 6, 143–162, https://doi.org/10.3390/met6070143
- Mohanavel, V., Rajan, K., Suresh Kumar, S., Udishkumar, S., Jayasekar, C. (2018). Effect of silicon carbide reinforcement on mechanical and physical properties of aluminum matrix composites, *Materials Today: Proceedings*, 5, 2938–2944, https://doi.org/10.1016/j.matpr.2018.01.089
- Murthy, H.C.A., Singh, S.K. (2015). Influence Of TiC Particulate Reinforcement On The Corrosion Behaviour of Al 6061 Metal Matrix Composites, *Advanced Materials Letters*, 6(7), 633–640, https://doi.org/10.5185/ amlett.2015.5654

- Padmavathi, C., Upadhyaya, A. (2010). Densification, Microstructure and Properties of Supersolidus Liquid Phase Sintered 6711Al-SiC Metal Matrix Composites, *Science of Sintering*, 42, 363–382, https://doi.org/10.2298/ SOS1003363P
- Patel, M., Singh, M.K., Sahu ,S.K. (2020). Abrasive wear behavior of SiC particulate reinforced AA5052 metal matrix composite, *Materials Today*, 33(8), https://doi.org/10.1016/j.matpr.2020.03.572
- Pieczonka, T., Kazior, J., Szewczyk-Nykiel, A., Hebda, M., Nykiel, M. (2012). Effect of atmosphere on sintering of Alumix 431D powder, *Powder Metallurgy*, 55(5), 354–360, https://doi.org/10.1179/1743290112Y.000000015
- Rai, R.N., Saha, S.C., Datta, G.L., Chakraborty, M., Studies on synthesis of in-situ Al-TiC metal matrix composites, 4th International Conference on Advances in Solidification Processes (ICASP-4). 2016, 117, 012042K, https://doi. org/10.1088/1757-899X/117/1/012042
- Reddy, V., Kumar, G.S., Krishnudu, D.M., Rao, H.R. (2020). Mechanical and wear performances of aluminium-based metal matrix composites, *Journal of Bio-and Tribo-Corrosion*, 6(3), 1–16, https://doi.org/10.1007/s40735-020-00379-2
- Roy, M., Venkataraman, B., Bhanuprasad, V.V., Mahajan, Y.R., Sundararajan, G. (1992). The Effect of Particulate Reinforcement on the Sliding Wear Behavior of Aluminum Matrix Composites, *Metallurgical and Materials Transactions A*, 23A, 2833–2847.
- Rudianto, H., Jang, G.J., Yang, S.S., Kim, Y.J., Dlouh, I. (2015). Effect of SiC particles on sinterability of Al-Zn-Mg-Cu P/M alloy, *Archives of Metallurgy and Materials*, 60(2), 1383–1385, https://doi.org/10.1515/amm-2015-0136
- Rudianto, H., Jang, G.J., Yang, S.S., Kim, Y.J., Dlouh, I. (2015). Evaluation of Sintering Behavior of Premix Al-Zn-Mg-Cu Alloy Powder, *Advances in Materials Science and Engineering*, 2, 1–8, https://doi.org/10.1155/2015/987687
- Sachin, R., Vamshi Krishna, S., Anil Kumar, S., Karthikeyan, R., Saidamma, K., Sunil Kumar Reddy, K. (2022). Corrosion and wear behavior of AMMCs, a review, *Materials Today: Proceedings*, 62(6), 4140–4146.
- Sambathkumar, M., Navaneethakrishnan, P., Ponappa, K., Sasikumar, K.S.K. (2016). Mechanical and corrosion behavior of Al7075 (hybrid) metal matrix composites by two step stir casting process, *Latin American Journal* of Solids and Structures, 14(2), 243–255, https://doi.org/10.1590/1679-78253132
- Vani, V.V., Chak, S.K. (2018). The effect of process parameters in Aluminum Metal Matrix Composites with Powder Metallurgy, *Manufacturing Review*, 5(7), 1–13, https://doi.org/10.1051/mfreview/2018001
- Verma, A.S., Sumankant, Suri, N.M., Yashpal, K. (2015). Corrosion Behavior of Aluminum base Particulate Metal Matrix Composites: A review, *Materials Today: Proceedings*, 2, 2840–2851, https://doi.org/10.1016/j. matpr.2015.07.299
- Zakaria, H.M. (2014). Microstructural and corrosion behavior of Al/SiC metal matrix composites, *Ain Shams Engineering Journal*, 5, 831–838, https:// doi.org/10.1016/j.asej.2014.03.003