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# Structure of EN AW-Al Cu4Mg1(A) composite materials reinforced with the Ti(C,N) ceramic particles

**A. Włodarczyk-Fligier*, L.A. Dobrzański, J. Konieczny**
Institute of Engineering Materials and Biomaterials, Silesian University of Technology, ul. Konarskiego 18a, 44-100 Gliwice, Poland
* Corresponding e-mail address: anna.wlodarczyk@polsl.pl

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**Materials**

## ABSTRACT

**Purpose:** The purpose of the paper is to show and compare of modern method composite materials with aluminium alloy matrix reinforced by Ti(C,N) particles manufacturing.
**Design/methodology/approach:** Powders of the starting materials were wet mixed in the laboratory vibratory ball mill to obtain the uniform distribution of the reinforcement particles in the matrix. The mixed powders were then dried in the air. The components were initially compacted at cold state in a die with the diameter of Ø 26 mm in the laboratory vertical unidirectional press – with a capacity of 350 kN. The selected compacting load was sufficient to obtain prepregs which would not crumble and at the same time would not be deformed too much, which would also have the adverse effect on their quality, as the excessive air pressure in the closed pores causes breaking the prepreg up when it is taken out from the die. The obtained PM compacts were heated to a temperature of 480-500˚C and finally extruded – with the extrusion pressure of 500 kN.
**Findings:** The received results show the possibility of obtaining the new composite materials with required structure joining positive properties composite materials components.
**Practical implications:** Tested composite materials can be applied among the others in automotive industry but it requires additional researches.
**Originality/value:** It was demonstrated structure of the extruded composite materials with the EN AW-Al Cu4Mg1(A) alloy matrix may be formed by the dispersion hardening with the Ti(C,N) particles in various portions and by the precipitation hardening of the matrix.
**Keywords:** Aluminium alloy; Composite materials; Powder metallurgy

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## 1. Introduction

Composites with an aluminium alloy matrix are a group of materials which due to their properties are more and more frequently used in modern engineering constructions [1, 2].

The metal matrix composite can be reinforced with particles, dispersoids or fibres. However, the biggest interest in composite materials is observed for those reinforced with hard ceramic particles due to the possibility of controlling their tribological-, heat- or mechanical properties by selection of the volume fractions, size, and distribution of the reinforcing particles in the matrix [3-7].

Aluminium matrix composites reinforced with ceramic particles (Ti(C,N), $Al_2O_3$, SiC) are gradually being implemented into production in electronic, military, aerospace, automotive or aircraft industries, first and foremost due to high resistance to friction wear [7-19, 23-30].

Powder metallurgy (PM) is thought to be the most common production technique for MMC's. One of the advantages of PM compared to casting is having better control on the microstructure, where better distribution of the reinforcement is possible in PM compacts. An important advantage of this method is its low processing temperature compared to melting techniques. Therefore, interaction between the matrix and the reinforcement phases is prevented. On the other hand, good distribution of the reinforcing particles can be achieved [7, 20, 31-32].

Deformation behaviour at extrusion temperature is dependent on many metallurgical and technological factors, e.g.: temperature, flow rate, and extrusion ratio. The advantage of extrusion process is possibility of making extruded products with high dimensional accuracy. Using the extrusion process it is possible to fabricate products with different geometries like solid and hollow profiles, with a fixed or varying transverse section. There are also some shortcomings of the extrusion process, and thus shortcomings of the extruded products, which are characteristic of the significant variations of their properties along their axis, and especially in their transverse section which are connected with the various degree of deformation during the extrusion process. Fabrication of the composite materials is focused on obtaining materials with improved properties compared to the matrix material [21].

Factor determining the mechanical properties of composite materials produced is the structure of interfacial composite. An important group of phase separation boundaries are the boundaries that are formed between the metal material and ceramic material [33].

The goal of the work is to investigate the structure, of the composite materials with the EN AW-AlCuMg4 (A) aluminium alloy based matrix reinforced with the ceramic particles of the Ti(C,N) phases with various weight ratios.

## 2. Experimental procedure

Examinations were made of the composite materials with the EN AW-AlCu4Mg1(A) aluminium alloy matrix with the chemical composition specified in Table 1, reinforced with the Ti(C,N) ceramic particles with the weight ratios of 5, 10 and 15% (ratio by volume 2.74%, 5.62%, 8.65% respectively).

Table 1.
Chemical composition of EN AW-AlCu4Mg1(A) aluminium alloy, % vol.[34]

| Si | Fe | Cu | Mn | Mg | Cr | Zn | Ti | the others | Al |
|---|---|---|---|---|---|---|---|---|---|
| 0.24 | 0.1 | 1.2-1.5 | 0.1-0.3 | 1.9-2.9 | 0.04 | 0.10 | 0.09 | 0.20 | rest |

It was found out that particles of powders used for fabrication of composite materials were irregular in shape and their size did not exceed 75 μm for the EN AW-AlCu4Mg1(A) powder and 25 μm for the Ti(C,N) powder (Table 2).

Table 2.
Particles size of powders used to investigated composites production

| Powder type | EN AW-AlCu4Mg1(A) | Ti(C,N) |
|---|---|---|
| Particle size in μm | ≤ 75 | ≤ 25 |

Powders of the starting materials were wet mixed (methanol slurry) in the laboratory vibratory ball mill to obtain the uniform distribution of the reinforcement particles in the matrix. The mixed powders were then dried in the air.

The weighed matrix and reinforcement powders were wet mixed together (methanol slurry) in the laboratory vibrating ball mill for 2 h to obtain the uniform distribution of the reinforcement particles in the matrix, and also to avoid development of the reinforcement particles clusters.

Aluminium containers were filled with the obtained mixtures. The powders mixtures in the containers were thickened initially (compacted) in the O.D. 26 mm die in the laboratory press with the computer load logging.

The following compacting process parameters were used:

- unidirectional, uniaxial compacting,
- room temperature,
- 350 kN load.

The selected compacting load was sufficient to obtain prepregs which would not crumble and at the same time would not be deformed too much, which would also have the adverse effect on their quality, as the excessive air pressure in the closed pores causes breaking the prepreg up when it is taken out from the die.

Density of extruded specimens was estimated with Archimedean principle, by determining the specimen mass and volume, and basing on the apparent loss of weight after immersing the specimen in water.

Table 3 presents results of density measurements. One can see that for all produced materials density is near to the theoretical one but existing differences indicate presence of porosity.

Aluminium containers filled with the compacted composite powders featured the charge for extrusion. These prepregs were heated to the temperature of 480-500°C and were extruded at 500 kN load. The die walls were lubricated with the zinc stearate to attain slide during charge extrusion. The O.D. 8 mm bars were obtained as the final product, enclosed in a thin aluminium sheath.

Metallographic examinations of the composite materials with the EN AW-Al Cu4Mg1(A) aluminium alloy matrix reinforced with the Ti(C,N) particles were carried out on LEICA MEF4A optical microscope; metallographic photographs were taken of sections transverse and longitudinal in respect to the extrusion direction. The specimens were etched in 5% HF. However, morphology examination of the starting powders and measurement of the powder particles sizes were carried out on OPTON (SEM) DSM 940 scanning electron microscope.

Diffraction study and structure of thin films made on transmission electron microscopy JEOL JEM 3010UHR with accelerating voltage of 300 kV. Thin films made of electro-cut tiles in cross section, with a thickness of about 1 mm, which were cut out circles with a diameter of 3 mm, their pre-polished surface, mechanically thinned on Disc Grinder to a thickness of about 80 microns and ion polished using equipment from Gatan.

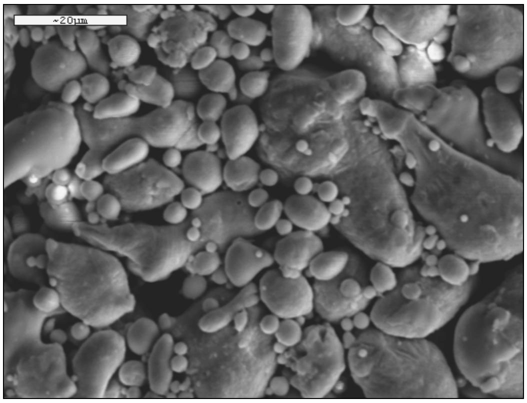
Table 3.
Density measured for investigated materials

| Material | Theoretical density, g/cm$^3$ | Measured density, g/cm$^3$ | Ratio of real density to the theoretical density, % |
|---|---|---|---|
| EN AW-Al Cu4Mg1(A) | 2.78 | 2.76 | 99.28 |
| EN AW- Al Cu4Mg1(A)/5%Ti(C,N) | 2.9 | 2.88 | 99.31 |
| EN AW- Al Cu4Mg1(A)/10%Ti(C,N) | 3.02 | 2.98 | 98.67 |
| EN AW- Al Cu4Mg1(A)/15%Ti(C,N) | 3.14 | 3.09 | 98.4 |

## 3. Results and discussion

Sizes of the EN AW- Al Cu4Mg1(A) aluminium alloy powder and of the reinforcing Ti(C,N) powder particles were determined based on SEM observations and are shown in Table 2 and their morphology is presented in Figure 1.

a)



b)

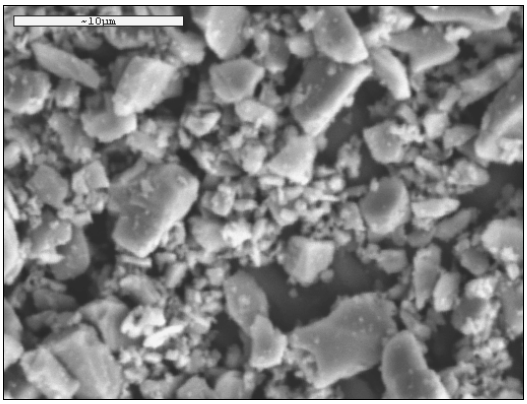
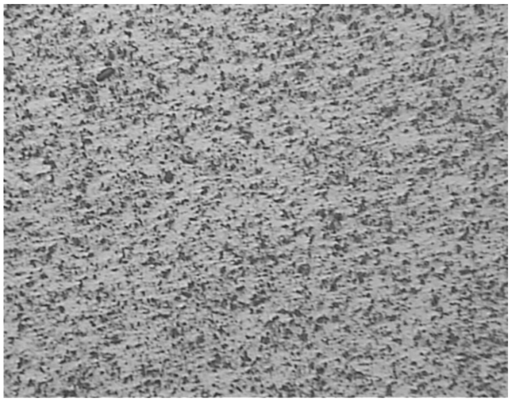


Fig. 1. Morphology of powders: a) aluminium alloy EN AW-AlCu4Mg1(A), b) Ti(C,N)

Based on observation structures on light microscopy, it was found that the composite has a high heterogeneity of distribution of reinforcement particles on the longitudinal section (Fig. 2b). Bands reinforcement particles arranged in lines are consistent with the direction of extrusion. Similar heterogeneity in the structure characteristic of the coextrusion process was obtained in [24].

a)

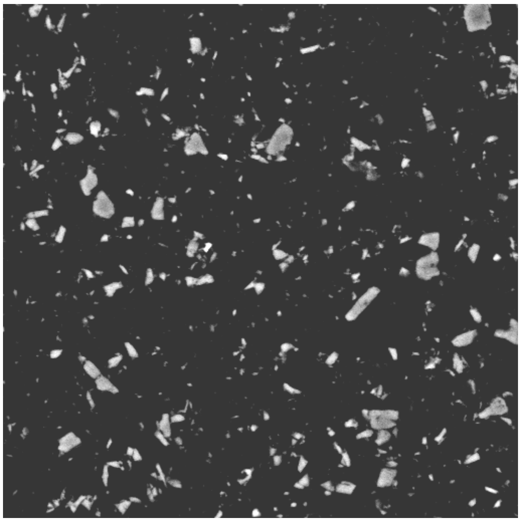


b)

Fig. 2. Section of aluminium alloy matrix composite materials with Ti(C,N) particles: a) longitudinal section, b) cross section

The metallographic examinations of both investigated composite materials make it possible to observe the homogeneous distribution of the reinforcing material in the matrix. In the case of material manufactured by extrusion method banding of the reinforcing particles parallel to the extrusion direction was noted on the longitudinal microsections (Fig. 3).

a)



b)

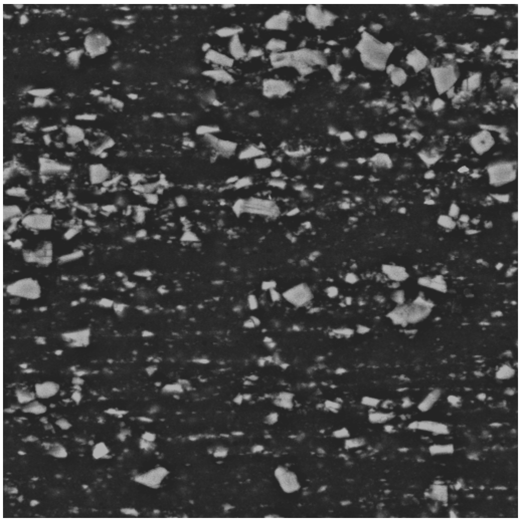
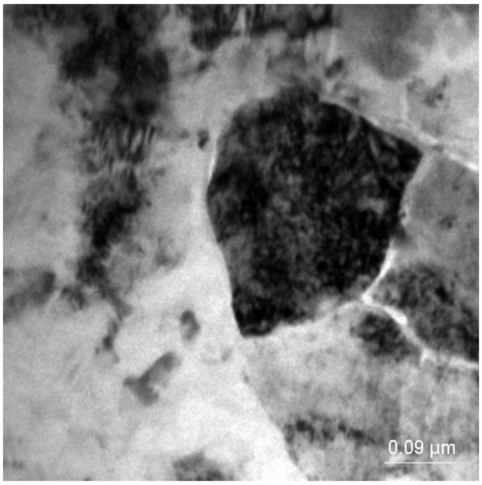


Fig. 3. Section of etched aluminium alloy matrix composite materials with Ti(C,N) particles, a) cross section, b) longitudinal section, SEM magnification 200x

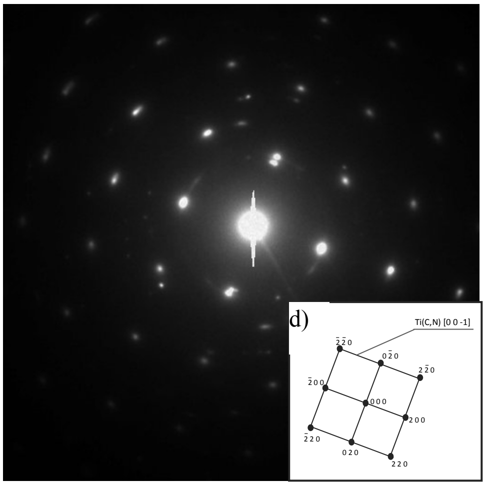
Moreover there were observed agglomerations of reinforcement particles, their segregation, and nonnumerous pores probably coming from not exact intermixing of aluminium alloy powder with reinforcement particles and small deformation level during extrusion.

Examinations of the composite extruded at temperature of 480-500°C at 500 kN confirmed presence of the reinforcement particle (Figs. 4a and c) of TiC phase crystallizing in the cubic crystal system (Fm-3m) with the lattice parameters a=b=c=4.328 Ǻ (Fig. 4b) in Al matrix. Reinforcing particle size of about 0.3 μ m, is set on the border of the matrix grains of the alloy EN AW-Al Cu4Mg1 (A).

a)




b)




c)

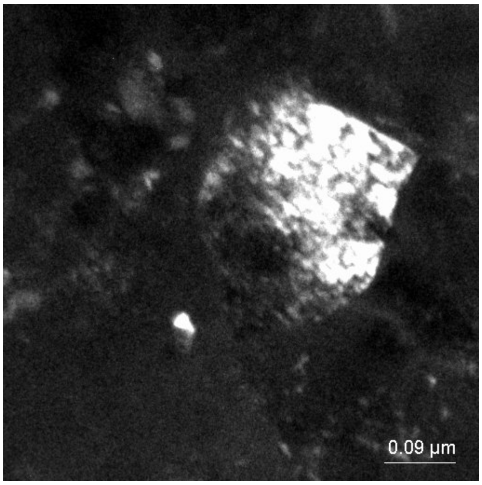



Fig. 4. Microstructure of EN AW-Al Cu4Mg1(A)+ Ti(C,N) composite a) bright field image; b) diffraction pattern from the area as in Fig. a; d) solution of the diffraction pattern from Fig. b; c) dark field image from 200 reflection of Ti(C,N) (Fm-3m S.G.)

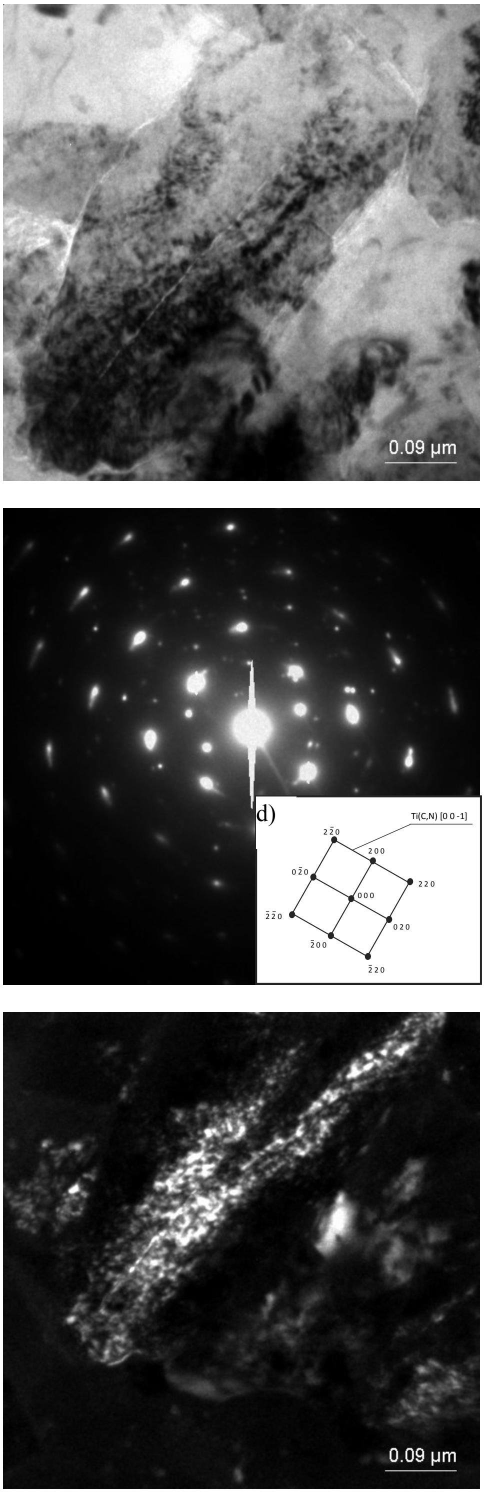



Fig. 5. Microstructure of EN AW-Al Cu4Mg1(A)+ Ti(C,N) composite a) bright field image; b) diffraction pattern from the area as in Fig. a; d) solution of the diffraction pattern from Fig. b; c) dark field image from $\bar{2}20$ reflection of TiN (Fm-3m S.G.)

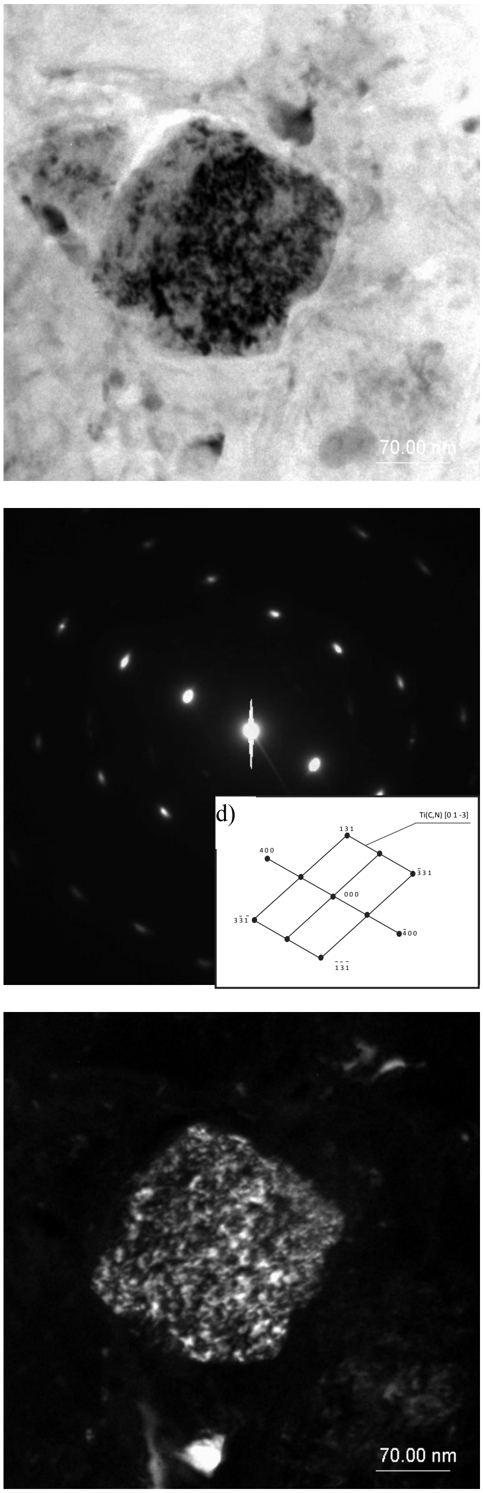



Fig. 6. Microstructure of EN AW-Al Cu4Mg1(A)+ Ti(C,N) composite a) bright field image; b) diffraction pattern from the area as in Fig. a; d) solution of the diffraction pattern from Fig. b; c) dark field image from $\bar{4}00$ reflection of Ti(C,N) (Fm-3m S.G.)

a) b) c)

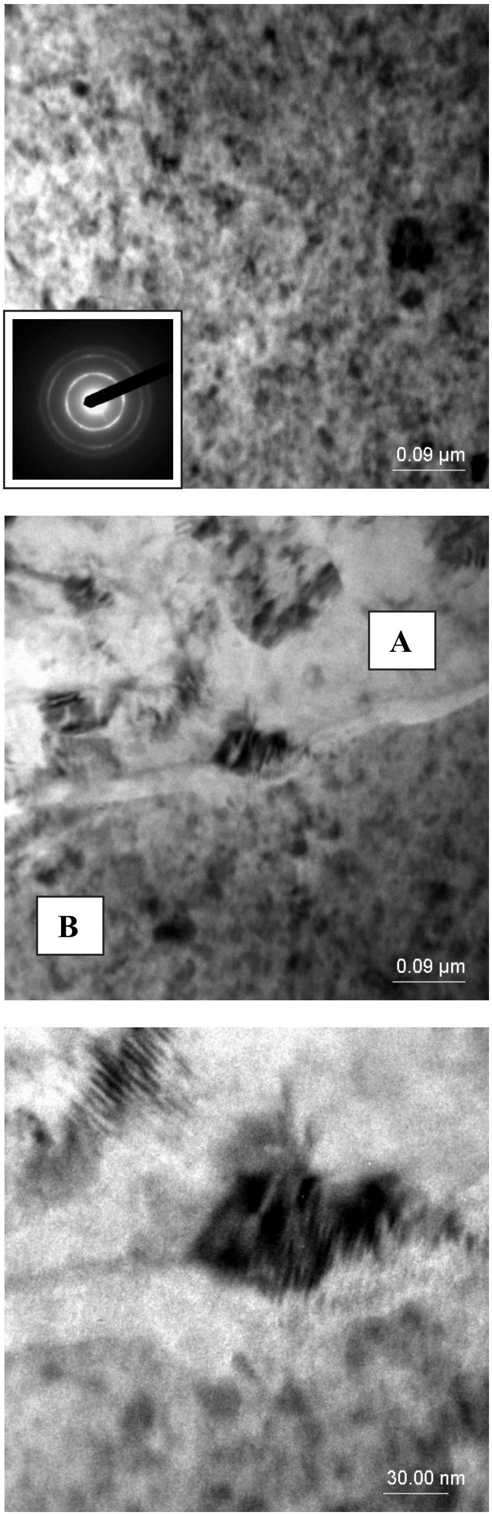



Fig. 7. Microstructure of EN AW-Al Cu4Mg1(A)+ Ti(C,N) composite a)-c) bright field image; visible on the diffraction rings originating from the TiN particles (200), (311), (400)

Enhancing particles should be hard, as well as small, high density, uniformly distributed in the volume of the alloy and at least partially coherent. Precipitations should not have sharp edges and should not form the matrix grain boundaries continuous film. This prevents the nucleation of cracks and their spread.

In the microstructure of the tested composite dominate reinforcing spherically shaped (Fig. 4, Fig 6) and longitudinal (Fig. 5) particles. The average particle size reinforcement Ti(C, N) is 0.271 μm but the length of the particles of elongated shape almost 0.7 μm.

Figure 5 presents the big reinforcement particle of Ti(C, N) phase in Al matrix crystallizing in the cubic crystal system (Fm-3m) with the lattice parameters a=b=c=4.235 Ǻ (Fig. 5). The longitudinal shape of the separation is unfavourable due to the weakening of the strength properties. Along the grain crack nucleation can take place and then spread.

On the other hand, Figure 6a presents another microstructure area with the reinforcement particle of Ti(C,N) phase crystallizing in the cubic crystal system (Fm-3m) with the lattice parameters a=b=c=4.235 Ǻ (Fig. 6b) in Al matrix. Just as in Fig. 4 the particle has a shape similar to an oval about the size of about 0.3 μm embedded in the matrix alloy EN AW-Al Cu4Mg1 (A).

In the Figure 7 one can see microstructure area with the very small reinforcement particle of Ti(C,N) phase. Just as in Figure 4 particles are embedded of a grain boundary (Fig. 7b), which separates the two areas A – where there are larger reinforcing particles, B – the area with particles of smaller diameter. This is another proof of the heterogeneity of the structure of the composite.

## 4. Conclusions

Basing on the structural examinations carried out of the composite materials with the EN AW-AlCu4Mg1(A) aluminium alloy matrix reinforced with the Ti(C,N) particles the homogeneity of their distribution in the matrix was revealed, as well as the fact that during their extrusion the directed structure develops oriented according to the extrusion direction.

The directed structure oriented corresponding to the extrusion direction developed during the extrusion process. Density for all produced materials is near to the theoretical one but existing differences indicate presence of porosity.

Based on observations made on the transmission microscope, it was found that the reinforcement particles Ti (C, N) are usually placed on the border of the matrix grains. Dominated by particles with spherical shape similar to but it is also observed in the shape of elongated particles.

## References

[1] B. Torres, H. Lieblich, J. Ibanez, A. Garcia-Escorial, Mechanical properties of some PM aluminide and silicide reinforced 2124 aluminium matrix composites, Scripta Materialia 47/1 (2002) 45-49.

[2] A. Jimenez-Morales, E.M. Ruiz-Navas, J.B. Fogagnolo, J.M. Torralba, Corrosion resistance of 6061 aluminium base composite materials, Advances in Materials and Processing Technologies (2003) 1267-1270.
[3] S.C. Tjong, Z.Y. Mal, Microstructural and mechanical characteristics of in situ metal matrix composites, Materials Science and Engineering 29 (2000) 49-113.
[4] M. Dyzia, J. Śleziona, Aluminium matrix composites reinforced with AlN particles formed by in situ reaction, Archives of Materials Science and Engineering 31/1 (2008) 17-20.
[5] G.E. Kiourtsidis, S.M. Skolianos, E.G. Pavlidou, A study on pitting behaviour of AA2024/$SiC_p$ composites using the double cycle polarization technique, Corrosion Science 41 (1999) 1185-1203.
[6] J.-W. Yeh, S.-Y. Yuan, Ch.-H. Peng, A reciprocating extrusion process for producing hypereutectic Al - 20 wt. % Si wrought alloys, Materials Science and Engineering A 252 (1998) 212-216.
[7] M. Rahimian, N. Ehsani N. Parvin, H. Baharvandi, The effect of particle size, sintering temperature and sintering time on the properties of Al-$Al_2O_3$ composites, made by powder metallurgy, Journal of Materials Processing Technology 209 (2009) 5387-5393.
[8] A. Włodarczyk-Fligier, L.A. Dobrzański, M. Adamiak, Influence of heat treatment on properties and corrosion resistance of Al-composite, Journal of Achievements in Materials and Manufacturing Engineering 21/1 (2007) 55-58.
[9] L.A. Dobrzański, A. Włodarczyk, M. Adamiak, Composite materials based on EN AW-Al Cu4Mg1(A) aluminium alloy reinforced with the Ti(C,N) ceramic particles, Materials Science Forum 530-531 (2006) 243-248.
[10] L.A Dobrzański, A. Włodarczyk-Fligier, Matrix composite materials reinforced by ceramic particles, Proceedings of the 17th International Scientific Conference "Contemporary Achievements in Mechanics, Manufacturing and Materials Science" CAM3S'2011, Gliwice-Wrocław, 2011, 46 (in Polish).
[11] G.G. Kang, Y.H. Seo, The influence of fabrication parameters on the deformation behavior of the perform of metal-matrix composites during the squeeze-casting processes, Journal of Materials Processing Technology 61 (1996) 241-249.
[12] H.S. Chu, K.S. Liu, J.W. Yeh, Aging behavior and tensile properties of 6061Al-0.3µm $Al_2O_{3p}$ particle composites produced by reciprocating extrusion, Scripta Materialia 45 (2001) 541-546.
[13] J.M. Torralba, C.E. Costa, F. Velasco, P/M aluminium matrix composites: an overview, Journal of Materials Processing Technology 133 (2003) 203-206.
[14] S.I. Hong, Y.S. Seo, Effect of microstructure on wear behavior of Al-Mg-Si alloy matrix-10 vol.% $Al_2O_3$ composite, Materials Science and Engineering A 265 (1999) 29-41.
[15] Y.T. Kim, K. Ikeda, T. Murakami, Metal flow in porthole die extrusion of aluminium, Journal of Materials Processing Technology 121 (2002) 107-115.
[16] P.B. Silna-Maia, F. Velasco. N. Anton, C.E. Costa, W.C Zapata, Corrosion resistance of 2014 aluminium matrix composites reinforced with atomised $Ni_3Al$, Advanced Performance Materials 6 (1999) 117-121.
[17] A. Kostka, J. Lelątko, M. Gigla H. Morawiec, A. Janas, Structure of interface in Al-$TiB_2$ composite studied by TEM, Composites 2 (2002) 297-302.
[18] M. Dyzia, J. Śleziona, Aluminium matrix composites reinforced with AlN particles formed by in situ reaction, Archives of Materials Science and Engineering 31/1 (2008) 17-20.
[19] S.C. Tjong, Z.Y. Mal, Microstructural and mechanical characteristics of in situ metal matrix composites, Materials Science and Engineering 29 (2000) 49-113.
[20] M. Rahimian, N. Parvin, N. Ehsani, The effect of production parameters on microstructure and wear resistance of powder metallurgy Al-$Al_2O_3$ composite, Materials and Design 32 (2011) 1031-1038.
[21] L.A. Dobrzański, A. Włodarczyk, M. Adamiak, Structure and properties of PM composite materials based on EN AW-2124 aluminum alloy reinforced with the BN or $Al_2O_3$ ceramics particles, Journal of Materials Processing Technology 175/1-3 (2006) 186-191.
[22] H. Morawiec, A. Kostka, J. Lelątko, M. Gigla, A. Janas, Structure of interface in Al-TiC composite, Composites 1 (2001) 228-232.
[23] M. Adamiak, J.B. Fogagnolo, E.M. Ruiz-Navas, L.A. Dobrzański, J.M. Torralba, Mechanically milled MMC reinforced with intermetallics– the structure and properties, Proceedings of the International AMPT Conference, Dublin, Ireland, 2003, 1448.
[24] S.I. Hong, Y.S. Seo, Effect of microstructure on wear behavior of Al-Mg-Si alloy matrix-10 vol.% $Al_2O_3$ composite, Materials Science and Engineering A 265 (1999) 29-41.
[25] Y.T. Kim, K. Ikeda, T. Murakami, Metal flow in porthole die extrusion of aluminium, Journal of Materials Processing Technology 121 (2002) 107-115.
[26] P.B. Silna-Maia, F. Velasco. N. Anton, C.E. Costa, W.C. Zapata, Corrosion resistance of 2014 aluminium matrix composites reinforced with atomised $Ni_3Al$, Advanced Performance Materials 6 (1999) 117-127.
[27] S.C. Tjong, Z.Y. Mal, Microstructural and mechanical characteristics of in situ metal matrix composites, Materials Science and Engineering 29 (2000) 49-113.
[28] M. Dyzia, J. Śleziona, Aluminium matrix composites reinforced with AlN particles formed by in situ reaction, Archives of Materials Science and Engineering 31/1 (2008) 17-20.
[29] L.A. Dobrzański, A. Włodarczyk-Fligier, M. Adamiak, The influence of heat treatment on corrosion resistance of PM composite materials based on EN AW-Al Cu4Mg1 (A) aluminum alloy reinforced with the Ti(C,N) particles, Materials Science Forum 534-536 (2007) 845-848.
[30] G.E. Kiourtsidis, S.M. Skolianos, E.G. Pavlidou, A study on pitting behaviour of AA2024/SiCp composites using the double cycle polarization technique, Corrosion Science 41 (1999) 1185-1203.

[31] A. Włodarczyk-Fligier, L.A. Dobrzański, M. Kremzer, M. Adamiak, Manufacturing of aluminium matrix composite materials reinforced by $Al_2O_3$ particles, Journal of Achievements in Materials and Manufacturing Engineering 27/1 (2008) 99-102.
[32] L.A. Dobrzański, A. Włodarczyk-Fligier, M. Adamiak, Properties and corrosion resistance of PM composite materials based on EN AW-Al Cu4Mg1(A) aluminum alloy reinforced with the Ti(C,N) particles, Proceedings of the 11th International Scientific Conference "Contemporary Achievements in Mechanics, Manufacturing and Materials Science" CAM3S'2005, Gliwice-Zakopane, 2005, 289-295.
[33] L.A. Dobrzański, J. Konieczny, Effect of extrusion parameters on the heterogeneity of the structure and condition of the surface layer of aluminum profiles, Proceedings of the Scientific Conference "Materials, Mechanical and Manufacturing Engineering" M3E'2000, Gliwice, 2000, 63-66 (in Polish).
[34] PN-EN 573-3, Aluminium and aluminium alloys–Chemical compositions and plastic formed product types, 1998.