How to cite this article:

Author: Jolanta Cyboroń

Title of article: „Badanie stanu naprężeń własnych po obróbce ubytkowej materiału kompozytowego o osnowie z aluminium zawierającego dodatek ceramiczny" ("Residual stress analysis after machining in composite materials based on aluminum alloy with ceramic additive")

Mechanik, Vol. 91, No. 1 (2018): pages 28–30

DOI: https://doi.org/10.17814/mechanik.2018.1.4

BULLETIN OF THE INSTITUTE OF ADVANCED MANUFACTURING TECHNOLOGY

30-011 KRAKÓW, ul. Wrocławska 37a, POLAND, tel. +48 12 63 17 333, 63 17 100, fax +48 12 63 39 490, ios@ios.krakow.pl, www.ios.krakow.pl

Residual stress analysis after machining in composite materials based on aluminum alloy with ceramic additive

Badanie stanu naprężeń własnych po obróbce ubytkowej materiału kompozytowego o osnowie z aluminium zawierającego dodatek ceramiczny

JOLANTA CYBOROŃ *

The paper presents the results of structural studies of AlSi7Mg alloy with 5% vol. addition of silicon carbide (SiC), after the machining process using the alternative method including: electrical discharge machining (EDM), abrasive water jet (AWJ) and mechanical cutting. The article presents the possibilities of measuring the impact of selected machining techniques on the surface and subsurface layers. X-ray diffraction were used to determine the level and characters of the obtained residual stresses. The article presents the X-ray diffraction method in the grazing incidence X-ray diffraction technique (GIXD) used for the practical measurement of the range of changes within the surface layer formed, as a result of interaction between the tool and the surface of the material being processed.

KEYWORDS: residual stress, grazing incidence X-ray diffraction technique, aluminum alloy

Composites with an aluminum matrix alloys are a group of materials with physical and mechanical properties are allow to use in modern engineering materials. Strengthening with ceramic particles (e.g. SiC, Al_2O_3, Si_3N_4) enables improvement of selected strength parameters and resistance to abrasive wear [1–3]. However, large differences in the physical (different values of linear expansion coefficients of ceramics and metal) and mechanical properties of components in the composite materials based on AlSi7Mg-matrix and SiC particles caused to produce the residual stresses, mainly the second type. The high level of tensile residual stress of ceramic material, associated with its high hardness and low fracture toughness, can also lead to weak connections.

The problem is also in the shaping of metal matrix composite – MMC (Metal Matrix Composite). The cutting tools made of cemented carbides used for processing are subject to very high wear and do not provide the appropriate dimensional tolerance [4, 5]. The main purpose of the machining is shaping the new surface of the object, meeting specific quantitative and qualitative requirements. The condition of the material after processing is determined by residual stresses occurring in the surface layer.

The subject of the present article was to determine the impact of these treatment – carried out by the erosion method, water-abrasive jet and mechanical cutting – on the state and level of residual stresses in a composite material with AlSi7Mg matrix containing 5% vol. SiC.

Material for research

In these studies the material for testing was a composite material with a AlSi7Mg matrix, reinforced with 5% vol.SiC particles. The procedure for the preparation of aluminum matrix composites contain ceramic reinforcement by the suspension method is described in publications [6, 7].

The removal machining was carried out with the following methods: EDM method, abrasive-water jet and mechanical cutting. Parameters of individual machining processes have been selected (optimized) in such a way that the modified surface layer has the smallest possible thickness.

An EWEA35 machine tool equipped with a GETA 10 generator was used for electric discharge machining. The parameters for the machining process are given in the tab. I.

The test material was also subjected to a machining using a high pressure water jet cutter FORACON WS 5. A water pressure around 300 MPa and a feed rate f = 0.02 mm/s were used. In order to compare the different machining methods as a further tool, allowing the removal of

* Dr inż. Jolanta Cyboroń (jolanta.cyboron@ios.krakow.pl) – Instytut Zaawansowanych Technologii Wytwarzania, Kraków

excess composite material, a tool type 4AM grinding machine was used, equipped with diamond grinding type A1 (160÷200 μm) type AC 32 200/160. The machining was carried out at a cutting speed of 22 m/s, under cooling with using a 3% synthetic oil.

TABLE I. Electrical parameters of spark erosion machining

Machining type	Pulse on time t_i, μs	Pulse off time t_o, μs	Pulse fill factor η	Current amplitude I, A	Power supply voltage U_z, V
EDM	4	10	0.29	3	90

Fig. 1 shows the AlSi7Mg alloy + 5% vol. SiC and its cut offs. Samples were cut from a casted piston. They have got the following dimensions: 50 × 35 × 6 mm.

Stress measurements were made using an X-ray diffractometer from PANalitycal Empyrean using filtered Cu radiation (λ_{Cu} = 1.5406 Å). Values of residual stresses within individual material layers were calculated using g-sin^{2}ψ – Grazing Incidence X-ray Diffraction method (GIXD) [8].

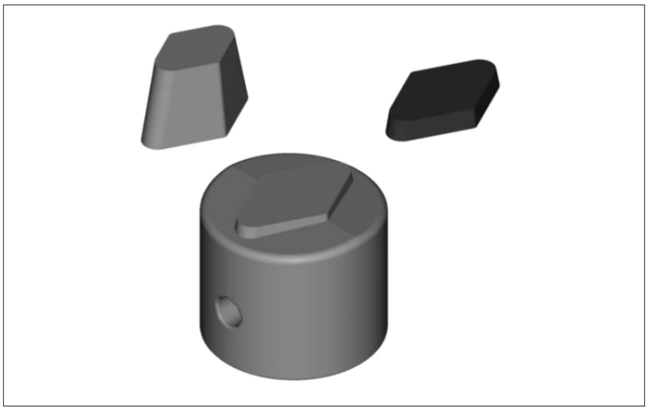

Fig. 1. Piston body made of material with AlSi7Mg composition + 5% vol. SiC along with the cut off head

Results

In order to investigate the residual stresses in the surface layer measurements with different measuring geometry, mainly BB (Bragga-Brentano) and Grazing Incidence X-ray Diffraction (GIXD) were carried out. Measurements of machined surfaces were carried out using both the erosion method and the abrasive water jet or mechanical cutting.

In diffraction methods, the volume, from which the result is obtained is determined by the effective penetration depth. This depth is defined as the thickness of the measuring layer z. The depth of X-ray radiation penetration depth in the case of the geometry BB is calculated by means of equation (1), and in the case of GIXD geometry – by the equation (2):

$$Z_{BB} = \frac{-\ln(1-G_x)}{2\mu}\sin\theta \qquad (1)$$

$$Z_{GIXD} = \frac{-\ln(1-G_x)}{\mu\left[\frac{1}{\sin\alpha}+\frac{1}{\sin(2\theta-\alpha)}\right]} \qquad (2)$$

where: μ – linear absorption coefficient (1/cm); θ – diffraction angle (°); G_x – informative fraction of diffracted X-ray beam (G_X = 0:95), α – grazing incidence angle (°).

The residual stresses in the material, within individual layers, were examined on the basis of the analysis of diffractograms obtained in the measuring geometry of GIXD. According to formulas (1) and (2), the effective penetration depth for various phases and different incidence angles were calculated.

Tab. II presents the effective penetration depth for individual phases occurring in a composite material based on AlSi7Mg matrix with the addition of 5% vol. SiC. Aluminum (Al), silicon carbide (SiC), silicon (Si) and magnesium silicide (Mg2Si) are included. The measurements were carried out for the incidence angles α = 1, 3, 5, 7 and 15°.

As it appears from tab. II, the effective measuring depth ranges from a few to several micrometers. This value depends mainly on the wavelength of the X-ray radiation and the linear absorption coefficient.

The application of the SKP method allows to determine the level of changes occurring in the surface layers of the material under the influence of various types of processing, as well as to determine the thickness of the layer, in which these changes occur.

For the final description of the surface layer after these machining techniques, the diffraction method for measuring residual stresses including the g-sin^{2}ψ method and the qualitative crystallographic texture index ($I_{theoretical} = I_{200}/I_{111}$ = = 0.46) was used. In tab. III, the results obtained for individual surfaces are summarized.

In the case of surfaces after electric discharge machining, there is a stress gradient in the individual material layers. The tests have shown the changing nature of stresses present in aluminum. In that case, at α = 15°, the applied cutting parameters and penetration depth are around 40 μm. In these region the residual stresses were around 84.2 MPa, which indicates their tensile nature. In other cases, stresses have the character of compressive stresses and were from –140.3 to –65.8 MPa, respectively.

TABLE II. Effective penetration depth, calculated for different phases depending on the measuring geometry (in the measurements, a lamp with a copper anode was used)

Geometry used	Effective penetration depth, μm, for			
	SiC μ = 151.3 cm^{-1}	Al μ = 135.6 cm^{-1}	Mg_2Si μ = 140.1 cm^{-1}	Si μ = 152.2 cm^{-1}
BB	do 100	up to 100	up to 140	up to 100
SKP, α = 1°	~3	~4	~4	~3
SKP, α = 3°	~10	~11	~12	~10
SKP, α = 5°	~16	~18	~17	~16
SKP, α = 7°	~21,5	~24	~23	~21,5
SKP, α = 15°	40	~48	45	40

TABLE III. Results of measurements of residual stresses in AlSi7Mg + 5% vol. SiC, determined for the Al phase (symbols used in the names of samples means: EDM – Electrical Discharge Machining, AWJ – Abrasive Waterjet Machining, C – Mechanical Cutting)

Sample name	Measurement geometry	Layer thickness *z*, µm	Stresses σ, MPa ($\Delta\sigma$ = 10±15%)	Texturing index-$I_{theoretical}$ = I_{200}/I_{111} = 0,46
Al-EDM	BB	up to 100	–100.6	1.47
	SKP, α = 1°	~4	–65.8	0.40
	SKP, α = 3°	~11	–140.3	0.04
	SKP, α = 5°	~18	–89.4	0.26
	SKP, α = 7°	~24	–83.1	0.16
	SKP, α = 15°	40	84.2	0.71
Al-AWJ	BB	up to 100	–201.2	0.27
	SKP, α = 1°	~4	–28.4	0.60
	SKP, α = 3°	~11	–53.6	1.03
	SKP, α = 5°	~18	–82.6	0.41
	SKP, α = 7°	~24	–93.0	0.82
	SKP, α = 15°	40	–216.3	0.66
Al-C	BB	up to 100	–57.2	0.37
	SKP, α = 1°	~4	–555.9	0.15
	SKP, α = 3°	~11	–119.5	0.59
	SKP, α = 5°	~18	–82.6	0.68
	SKP, α = 7°	~24	–46.2	0.35
	SKP, α = 15°	40	–62.4	0.55

The surface after machining with the abrasive water jet is characterized by the compressive stresses in the entire volume tested. The absolute values of stresses increase with the increase of penetration depth (they assume the smallest absolute values in the subsurface layers).

The surface after mechanical cutting is characterized by a high level of compressive residual stresses in the near surface layer (~4 µm) – this is related to a direct impact of the diamond wheel on the surface on the material being machined. As the penetration depth increases, the absolute value of stresses decreases.

Summary and Conclusions

The amount of residual stresses in the surface layer after the machining was estimated by the g-sin$^2\psi$ method. Obtained results indicate the possibility of using the discussed processing techniques – as alternative treatment methods – in the case of composites with metal matrix MMC.

The stresses induced by the cavity treatment show (mainly) the compression character.

The highest level of residual stresses (–555.9 MPa) was achieved in the near-surface layer with a thickness of approx. 4 µm in the case of surface after cutting with a tool grinder.

Absolute values of the residual stresses for the surface layer of the composite after cutting with the abrasive jet increase as the depth of penetration increases.

The method of investigating residual stresses by means of X-ray diffraction allows to analyze the effect of wasting on the material condition. This method can also be helpful when using a different type of treatment, e.g. burnishing, nitriding or carburizing.

REFERENCES

1. Devaraju A., Kumar A., Kotiveerachari B. "Influence of addition of Grp/Al2O3p with SiCp on wear properties of aluminum alloy 6061-T6 hybrid composites via friction stir processing". *Transactions of Nonferrous Metals Society of China*. 23 (2013): pp. 1275–1280.
2. Lieblich M., Corrochano J., Ibáñez J., Vadillo V., Walker J.C., Rainforth W.M. "Subsurface modifications in powder metallurgy aluminum alloy composites reinforced with intermetallic MoSi2 particles under dry sliding wear". *Wear*. 309 (2014): pp. 126–133.
3. Mathan Kumar N., Senthil Kumaran S., Kumaraswamidhas L.A. "Wear behaviour of Al 261 8 alloy reinforced with Si3N4, AlN and ZrB2 in situ composites at elevated temperatures". *Alexandria Engineering Journal*. 55 (2016): pp. 19–36.
4. Manna A., Bhattacharayya B. A study on machinability of Al/SiC-MMC Journal of Materials Processing Technology 140 (2003): pp. 711–716.
5. Lin J.T., Bhattacharyya D., Lane C. "Case study machinability of a silicon carbide reinforced matrix composite aluminum metal". *Wear*. 181–183 (1995): pp. 883–888.
6. Dolata A.J., Dyzia M. "Aspects of fabrication aluminum matrix heterophase composites by suspension method". *IOP Conf. Series: Materials Science and Engineering*. 35 (2012): pp. 1–7.
7. Dyzia M. "AlSi7Mg/SiC and heterophase SiCP+CG composite for use in cylinder-piston system of air compressor". *Solid State Phenomena*. 176 (2011): pp. 49–54.
8. Skrzypek S. *„Nowe możliwości pomiaru makro-naprężeń własnych w materiałach przy zastosowaniu dyfrakcji promieniowania X w geometrii stałego kąta padania*". Kraków: Wydawnictwo Naukowo- Dydaktyczne AGH, 2002. ■

Research work has been undertaken as part of the project "Development of the composite phase composition based on the AlSi alloy in terms of the ability to shape working surfaces of pistons", KOMPCAST, No. PBS1/B6/13/2013, and as part of the statutory activity of the Institute of Advanced Manufacturing Technologies (DS.17-3.3.2).

Translation of scientific articles, their computer composition and publishing them on the website www.mechanik.media.pl by original articles in Polish is a task financed from the funds of the Ministry of Science and Higher Education designated for dissemination of science.

Ministry of Science and Higher Education
Republic of Poland