

Geometric Features of a Multilayer Surface After Water Jet Cutting in Variable Cutting Conditions

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The paper presents the results of experimental work on the assessment of 3D geometry of surface stereometry obtained as a result of Water Jet (AWJ) water-abrasive beam cutting using an Eckert hydro-abrasive cutter. Studies of geometric structures were conducted using the Alicona microscope. 3D spatial roughness parameters such as S_a , S_q , S_{sk} , and S_{ku} were analyzed. The roughness parameters has been determined for 3 macro-areas of the multilayer structure surfaces combined as a result of the vulcanization process with an aluminium alloy surface (for representative surface of the aluminium alloy (B) and silicone (A), as well as the interphase surface (A/B)). The obtained experimental results were described by means of a 2nd degree regression function and the relevant determination coefficients were determined. All recorded characteristics of roughness changes showed an upward trend. The progressive nature of the changes concerned the entire range of input values as a function of the feed rate v_f for both analyzed mass expenditures of the Water Jet cut. The results of the research work are summarized in the technological function of the AWJ cutting conditions, such as the cutting speed and the mass flow of the abrasive material.

Keywords: Aluminium Alloy, Silicone, Water Jet Cutting, Surface Roughness, Surface Morphology

1 Introduction

Hydro-abrasive processing is listed as one of the newer and unconventional methods of material treatment that has found its application in industry. Depending on the intended purpose, there are two types of cutting heads: the water-jet-only cutting head (AWJ) and the abrasive water-jet cutting head (AWJ) featuring added abrasive material. The cutting energy is obtained by giving water a high level of kinetic energy. The speed reached by the water released from the nozzle can reach a value of up to 1000 m/s. Such a high speed is possible thanks to a high-pressure pump, which generates a pressure of up to 400 MPa. There are also types of pumps that increase the water pressure to 600 MPa. Water under such high pressure is released through the tube (nozzle), focusing the water jet beam on the material being cut, where due to a significant increase in energy, the flow of the jet leads to its decohesion [1][3][4][5].

Currently, hydro-abrasive treatment (AWJ) is widely used in the processing of various materials, such as titanium alloys, steel, brass, aluminium alloys, Inconel as well as stone, glass and all kinds of composites.

A schematic illustration of the AWJ head system is shown in Fig. 1. High-pressure water is a carrier for

the abrasive material. The momentum of the water carries the abrasive material particles and moves them through the tube focusing a high kinetic energy beam on the material being cut, which in contact with the processed material (strikes the material being processed) causes its separation and removal [6][7][8].

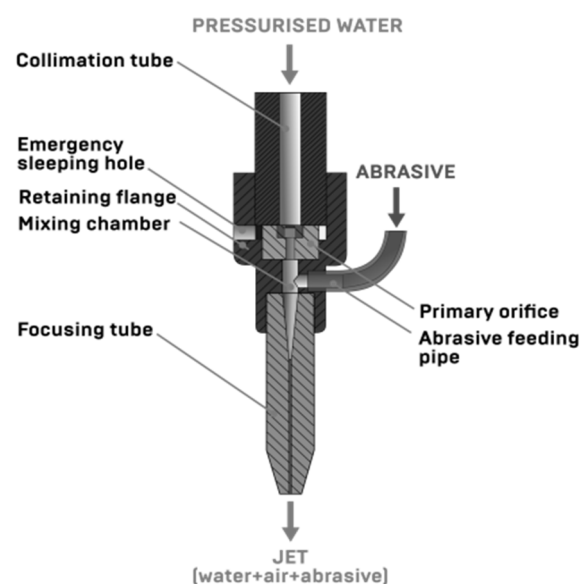


Fig. 1 Diagram of a nozzle used for hydro-abrasive cutting

The extensive application capabilities of the AWJ machining process in relation to the variety of cut materials and the lack of a heat impact zone make it an important tool in the process of cutting and constitution of geometrically complex cutting lines for composite materials, particularly layered structures, which are extremely inflexible and difficult to process using traditional machining processes [9][10][11].

An unfavourable phenomenon that occurs during hydro-abrasive processing is the deflection of the water-abrasive jet stream visible on the object's cut surface (Fig. 2). The deflection of the stream largely depends on the thickness of the cut material and the cutting speed (linear feed rate). This phenomenon results from the fact that a significant velocity of the water stream (kinetic energy) is lost in the upper part of the workpiece (initial cutting phase), and when reaching the material's lower layers, the "stream's force" is significantly weakened. As the thickness of the workpiece increases, the quality of the processed edge deteriorates significantly. This effect is shown in Fig. 2. This results in visible machining marks on the lower cut surface[12][13][14].

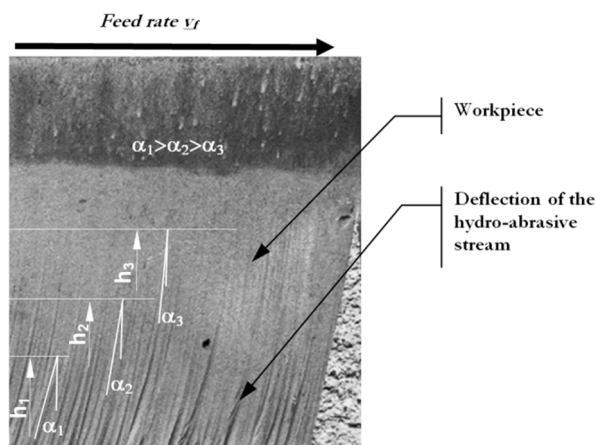


Fig. 2 Surface after the hydro-abrasive stream cutting process, the arrow indicates the cutting direction with the feed rate v_f

Composite and multi-layered materials as well as hybrid polymer compositions frequently require finishing. Conventional methods such as milling, drilling, etc. may cause defects on the processed composite surface, including delamination of the layers and surface degradation[15][16][17]. In addition, micro and nanoparticles are released during composite or bonded material processing, which are inhaled by the

operator. This negatively impacts the machine operator's health and the surrounding environment[18][18]. The authors of the paper [18] consider tribological issues in water jet processing. In particular, they analyze friction and wear between the cylinder and piston of high-pressure pumps treating them as a multilayer - multiwall system. Friction and wear is an important problem analyzed in the work [19][20] in jet processes, which significantly affect the efficiency, reliability and service life of the high-pressure pumps.

2 Research methodology

The aim of the experimental research was to analyse the impact of variable cutting parameters, such as: feed rate during hydro-abrasive cutting v_f [mm/min] and mass flow rate m_a [g/s] on the cut surface quality. The qualitative indicators were spatial roughness parameters S_a , S_q and coefficients describing the operating characteristics of the cut surfaces S_{sk} , S_{ku} . During the tests, a two-layer aluminium alloy AW-5754 - silicone structure, created through the use of the vulcanization technology of silicone and aluminium alloy AW-5754 under a high temperature, was subjected to the cutting process. The semi-product for cutting was a 500x500 mm plate, shown in Fig. 3.

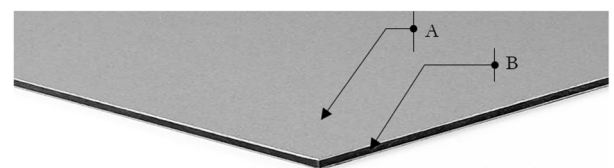


Fig. 3 Two-layer structure of aluminium alloy AW-5754 – silicone, prepared for hydro-abrasive processing, where the letter A denotes a layer of silicone, while the letter B denotes a layer of aluminium alloy AW-5754

The chemical composition of the aluminium alloy AW-5754 used is shown in Table 1. In the table, the chemical composition of the aluminum alloy is given by weight. The multilayer composite plate with the aluminium alloy AW-5754 - silicone structure and thickness $g=4$ mm was subjected to surface processing using abrasive paper in accordance with FEPA standard, gradation P240. The aluminium surface was then washed and degreased using a neutral pH chlorine solvent in order to remove any remaining metallic particles, grease and oxides. This also reduced the presence of potential corrosion sites.

Tab. 1 Chemical composition by weight of aluminium alloy AW-5754

Aluminium alloy AW-5754	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Zr
Chemical composition (%)	0.40	0.40	0.10	0.50	2.6	0.3	0.2	0.15	-

The silicone used for testing is a colourless MVQ material with a density of 1.25g/cm^3 . The hardness of the silicone was 60 ShA. The aluminium AW-5754 -

silicone structure was created on a Lema 301G hydraulic press with a built-in double heating plate.

These two materials were joined at 170°C over a period of 7 min. Press pressure on the silicone layer was even and equalled 40000 kg per 1 m² (40 MPa). The hybrid multilayer composition was cooled at ambient temperature (20°C).

2.1 Research model and test conditions

In order to conduct the experimental studies, a research model of the high-pressure cutting process was prepared in the aspect of analysing the improvement of surface roughness spatial parameters (Sa , Sq) and its performance characteristics described by the skewness coefficients Ssk and kurtosis Sku . The research model is shown in Fig. 4.

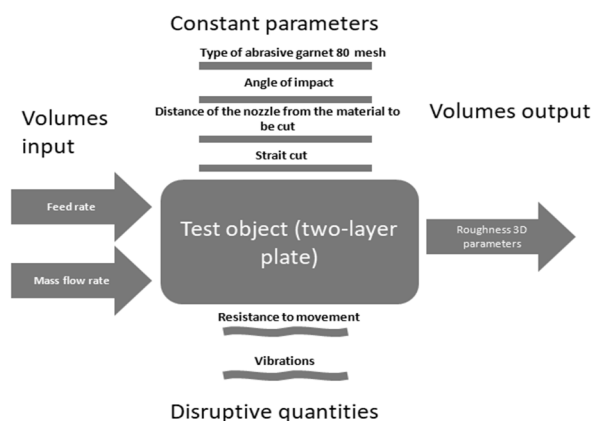


Fig. 4 Research model of the multilayer composition high-pressure hydro-abrasive cutting analysis

The research model takes into account the input, output, interference and constant values, which remain unchanged during the hydro-abrasive cutting process. Detailed quantitative and qualitative data of the input variables are presented in Table 2. The adopted input values were: cutting speed v_f [mm/min] and the abrasive material's mass flow rate m_a [g/s]. Disruptive quantities are the vibrations present during the cutting process and motion resistances arising from friction processes in guides and kinematic transmissions. The values adopted as constant included: the incidence angle of the water-abrasive mixture stream on the workpiece material equal to 90°, the abrasive material type (garnet 80 mesh), the pressure value p [MPa], and the distance of the nozzle from the cut material l [mm]. Garnet 80 mesh was used as the abrasive material applied in this process. The values analysed during the experiment were the output data of the assumed research model, which included spatial roughness parameters and operating parameters of the cutting surface.

2.2 Research workstation

The process of sample cutting was carried out on an Eckert Combo cutter, designed for thermal cutting and hydro-abrasive cutting. The abrasive water cutting

machines are numerically controlled machines for sheet metal cutting using the mounted cutting tools, which are: a clean water cutting head, a water and abrasive material cutting head, and a plasma torch. The hydro-abrasive cutting device is presented in Fig. 5.

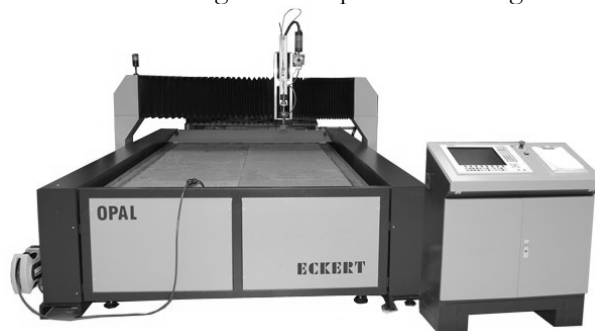


Fig. 5 Eckert Water Jet COMBO portal cutter used for performing the cutting process

The result of the cutting process were samples presented in Fig. 6. On the sample, the silicone layer was marked with the letter A and the aluminium alloy AW-5754 layer was described with the letter B. The dimensions of the samples' cutting surface were 5x30 mm and 5mm height, respectively. The samples were obtained from a plate executed following the technology described above.

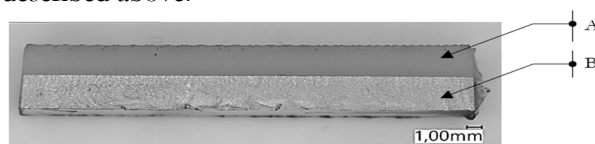


Fig. 6 The test sample where A is the silicone layer and B is the aluminium alloy AW-5754 layer

The samples cut on the Eckert Water Jet COMBO hydro-abrasive cutter were analysed using an Alicona Infinite Focus microscope. Alicona Infinite Focus is an optical 3D measurement system for easy, fast and automated measurement of a surface's geometric structure. Figure 7 presents the Alicona Infinite Focus G5 measurement system with graphically presented measurement data analysis and experimental result presentation capabilities.

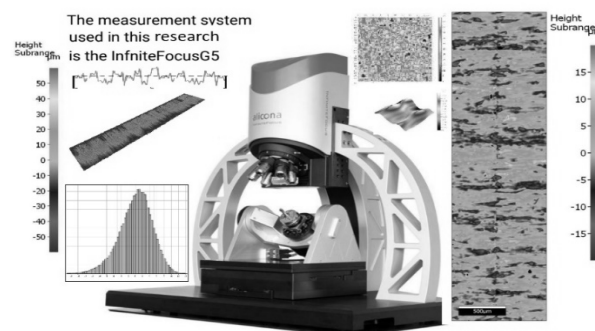


Fig. 7 Alicona Infinite Focus G5 optical measurement system with a CNC Control Table

Table 2 shows the list of cutting process input parameters used during the research tests. They are input variables of the adopted research model. The values of individual input variables were determined experimentally, based on prior studies and literature review

Tab. 2 Variable cutting process parameters

Mass flow rate m_a [g/s]	Sample number										
	1	2	3	4	5	6	7	8	9	10	11
0.8	Feed rate during cutting v_f [mm/min]										
	50	100	200	300	500	1000	1500	2000	2500	3000	3500
0.4	Sample number										
	1	2	3	4	5	6	7	8	9	10	11
0.4	Feed rate during cutting v_f [mm/min]										
	50	100	200	300	500	1000	1500	2000	2500	3000	3500

The following parameters were adopted as constant: nozzle diameter 0.7 mm, Garnet 80 mesh abrasive, 3 mm nozzle distance from the cut material, 100 mm nozzle length, stream angle of incidence in relation to the cut material 90° pump pressure 350 MPa. The abrasive mass flow rate m_a [g/s] and the speed of the feed motion rate during cutting v_f [mm/min] were adopted as variable parameters.

3 Experimental test results and discussion

The roughness measurements were performed at three sample heights. These areas were: the surface en-

on abrasive-water jet cutting. From the plate (Fig.3), test samples were cut using the AWJ process. The feed rate values v_f for the cut materials and the abrasive mass flow values are provided in Table 2.

compassing the aluminium alloy AW-5754, the interphase zone and the silicone surface (Fig. 8). Below are images of the samples used for the study from the Alicona microscope. These images were taken at the phase boundary. Smaller areas have dimensions of 0.612×0.612 mm. At the border of these materials, there is no significant irregularity that may result from material change. Fig. 8a shows monochrome imaging with a visible phase boundary of aluminium alloy AW-5754 – silicone, while Fig. 8b shows the maximum surface irregularity height at the phase boundary (A/B), where the letter A denotes the silicone layer and the letter B indicates the aluminium alloy AW-5754 layer.

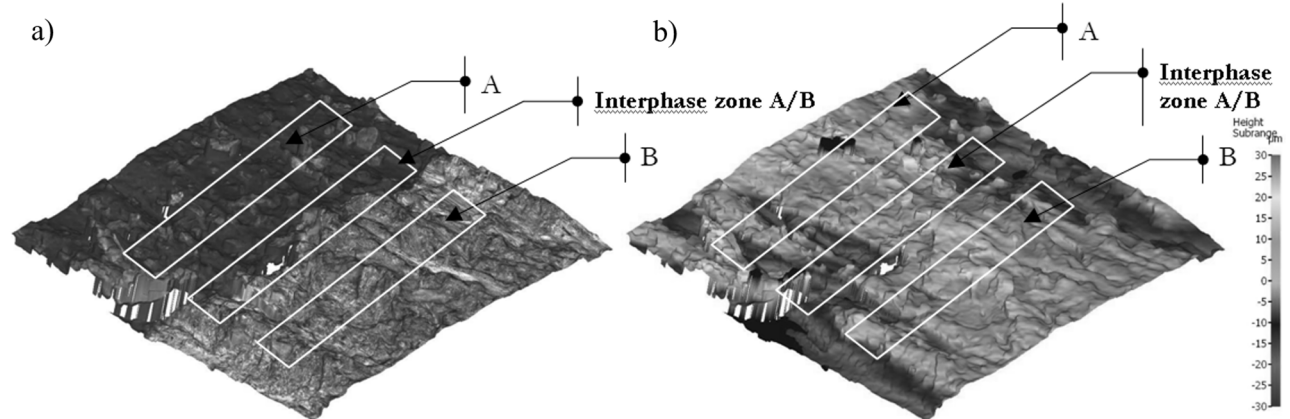


Fig. 8 Example microscopic imaging of the sample surface with dimensions of 0.612×0.612 mm made using the Alicona Infinite Focus G5 optical measuring system: a) monochrome imaging with a visible border of the phases of aluminium alloy AW-5754 – silicon (A/B), b) maximum heights of the height of surface irregularities at the phase boundary, where the letter A marks the silicone layer, and the letter B the layer of aluminium alloy AW-5754

Figure 9 shows an example of microscopic imaging of the interphase surface of samples (A/B) cut with different technological processing parameters. Fig. 9a describes the representative surface geometry obtained during cutting at a feed rate $v_f=1000$ mm/min at a mass flow rate of $m_a=0.4$ g/s. Fig. 9b shows the geometric structure of the cutting surface of a multi-layer structure composite obtained at twice the mass

flow rate, equal to $m_a=0.8$ g/s. The presented microscopic imagery allows to observe significant differences in the geometric structure of the cut surfaces, and the obtained measurement data allow to determine the level of significance of these differences. The preliminary analysis of the already presented imagery of surface irregularity distribution shows a significant

impact of the mass flow rate m_a on the geometric structure of the analysed surfaces and only a slight impact on changes in surface irregularity in the interphase zone at the interface of aluminium alloy AW-5754 – silicone (A/B) phases. In addition, there are significant

differences between the irregularity of the silicone A and aluminium alloy B surfaces. Both presented images were obtained at the feed speed $v_f = 1000$ mm/min.

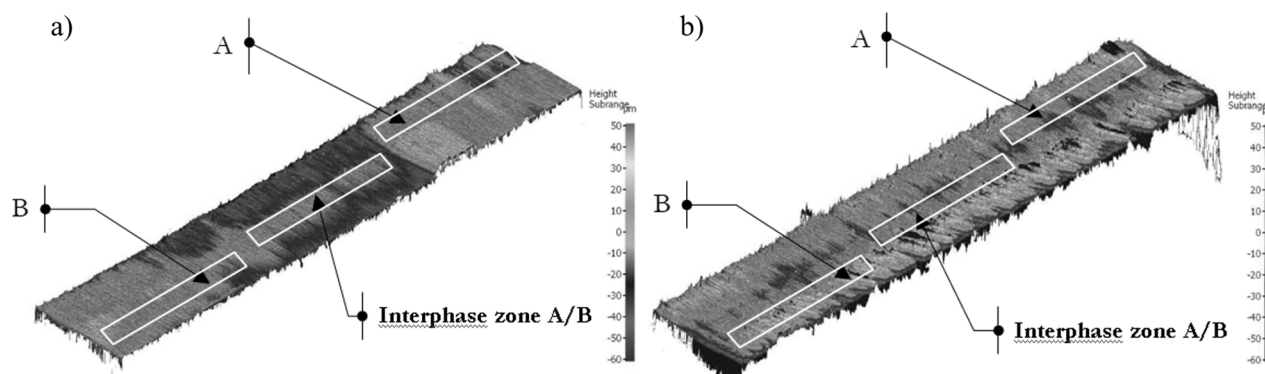


Fig. 9 Example microscopic imaging of the interphase surface (A/B) of samples cut with the following technological parameters: a) mass flow rate $m_a=0.4$ g/s, feed rate during cutting $v_f=1000$ mm/min, b) mass flow rate $m_a=0.8$ g/s, feed rate during cutting $v_f=1000$ mm/min, where the letter A marks the silicone layer, while the letter B marks the layer of aluminium alloy AW-5754, and A/B indicates the interphase zone

The presented images also allow to observe the transition between the joined materials A and B. Based on the tests conducted in accordance with Tab. 2 experimental tests, samples and surfaces were obtained that are the source of information on the analysed causal relationships. Based on the performed measurements, quantitative results of surface roughness parameters were obtained. The parameters chosen for analysis were: the $Sa[\mu m]$ parameter (average height of selected area) determined for the isolated, representative surface of the aluminium alloy (B) and silicone (A), as well as the interphase surface (A/B), as well as parameters describing the operational features of the surfaces constituted in the hydro-abrasive cutting process, such as the skewness coefficient Ssk and the asymmetry coefficient - kurtosis Sku . The obtained test results are graphically presented on graphs and mathematically, providing regression equations and R^2 determination coefficients that best describe the modelled causal relationships. The obtained functional relationships of the tested compounds and their graphic representations are presented in Fig. 10-21.

The graph presented in Fig. 10 shows the course of changes in the mean value of the parameter Sa for the interphase surface (A/B) at the boundary of the aluminium alloy AW-5754 – silicon phases from the selected measurement area as a function of the feed rate v_f . Two continuous lines of different colours, denoting different abrasive mass expenditures (0.4 g/s and 0.8 g/s), for the Al-Si interphase zone (A/B), were used to mark the approximating function against the background of experimental results - described with dashed lines, and functional relationships describing the analysed 3D spatial roughness relationship were

provided. In the following figure (Fig. 11) presents in green the parameters of the spatial surface roughness Sa of the aluminium alloy AW-5754 (B), cut with a mass expenditure $m_g=0.4$ g/s as a function of the feed rate v_f , and in red shows the surface cut with the mass expenditure $m_g=0.8$ g/s. Fig. 12 presents the same functional compounds specified for the silicone surface (A). Exponential functions were adopted as approximating functions, for which the determination coefficient value was the highest. For functional compounds presented in the graphs, the value of this coefficient was in the range of $R^2=0.451-0.737$. The relatively low determination coefficient value R^2 , which is a measure of the quality of the model's adjustment, shows what percentage of one variable explains the variability of the other variable. In the analysed case, this adjustment measure of a maximum value of 73.7% explains the variability of the obtained experimental data (Sa). It should also be noted that it is significantly higher for the course of changes in the mean roughness parameter value Sa on the surface of the aluminium alloy AW-5754 from the selected measuring area, obtained for different feed rates v_f than for the interphase zone (A/B) and silicone (A). Based on the obtained experimental test results, it can be indicated that for the lower value of mass expenditure $m_g=0.4$ g/s, the spatial roughness values Sq are approximately 12-15% higher than in the case of a higher expenditure of $m_g=0.8$ g/s.

The curves presented in Fig. 13 show the course of changes in the mean roughness parameter value Sq [μm] (Root-Mean-Square) for the interphase surface (A/B) at the aluminium alloy AW-5754 – silicon boundary, aluminium alloy AW-5754 (B) (Fig. 14) and

silicone (A) (Fig. 15) from the selected measuring area as a function of the feed rate v_f . Colours indicate the results obtained for two different abrasive mass expenditures $m_g=0.4$ g/s (green) and $m_g=0.8$ g/s (red). Experimental results - similarly to the S_a parameter - were approximated by exponential functions, taking into account the non-linear nature of the changes in the examined relationships. Based on the obtained results of experimental tests, it can be indicated that for the lower mass expenditure value $m_g=0.4$ g/s, the values of spatial roughness S_q are approximately 10% higher than in the case of a higher expenditure of $m_g=0.8$ g/s. Similarly to the S_a parameter, also for S_q the value of the determination coefficient is very low and is in the range of $R^2=0.430$ - 0.559 . This means that the assumed exponential model does not particularly precisely (low model quality) explain the shaping of the roughness parameter S_q .

Based on the curves of the roughness parameters (S_a , S_q), it is possible to determine the non-linear nature of the changes and the phenomenon of increasing roughness along with an the increasing feed rate v_f . It should also be added that the obtained characteristics show very similar courses in both qualitative and quantitative terms.

It can be concluded that an important issue is the multilayer structure's position relative to the hydro-abrasive stream. The multilayer structure of aluminium alloy AW-5754 - silicone was cut from the silicone side. As the cutting depth increases, the water-abrasive stream loses its velocity, which in turn affects a reduction in the energy that is required to cause decohesion in the deeper and much harder layers of the aluminium alloy AW-5754. This phenomenon results in a rougher surface in the lower parts of the aluminium alloy AW-5754.

Superior surface properties were observed in the upper area of the material, which consisted of silicone. As shown in Fig. 15, the roughness for silicone with an increase in feed rate v_f rises only slightly.

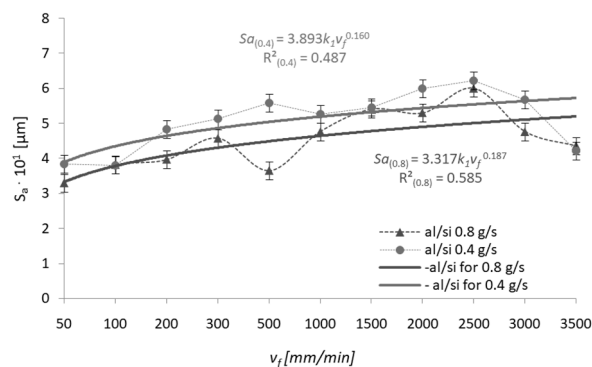


Fig. 10 Graph of changes in the mean value of the S_a parameter for the interphase surface (A/B) at the aluminium alloy AW-5754 – silicon boundary, from a selected measurement area as a function of the feed rate v_f

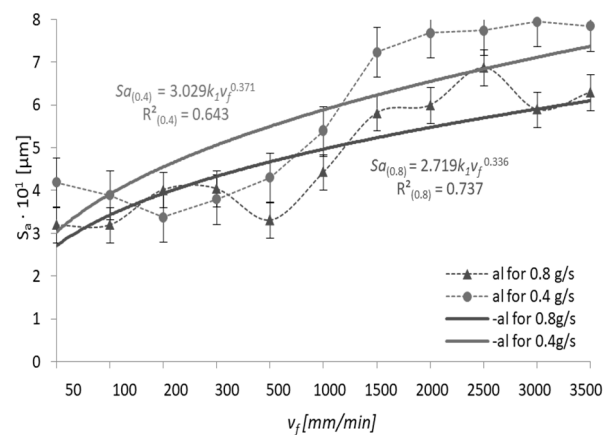


Fig. 11 Graph of changes in the mean value of the S_a roughness parameter for the aluminium alloy AW-5754 surface from a selected measuring area as a function of the feed rate v_f

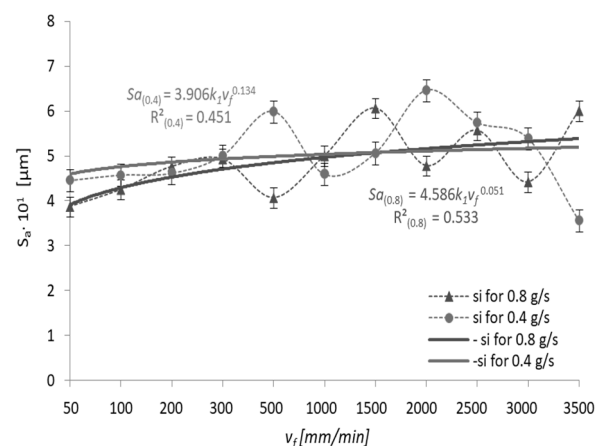


Fig. 12 Graph of changes in the mean value of the S_a roughness parameter for the silicone surface from a selected measuring area as a function of the feed rate v_f

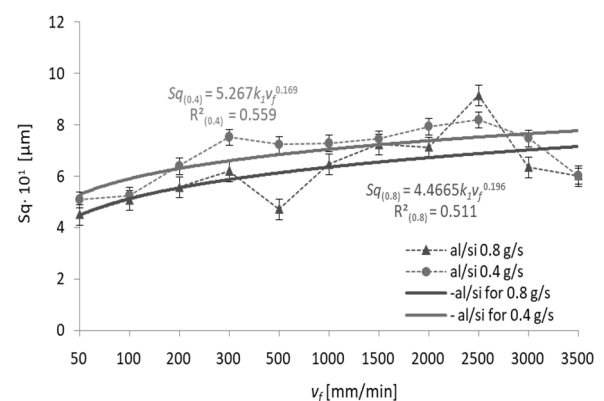


Fig. 13 Graph of changes in the mean value of the roughness parameter S_q [μm] for the interphase surface at the aluminium alloy AW-5754 – silicon boundary, from a selected measurement area as a function of the feed rate v_f S_q [μm] Root-Mean-Square

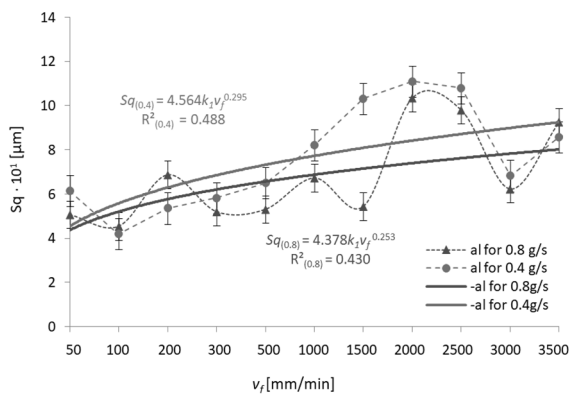


Fig. 14 Graph of changes in the mean value of the roughness parameter Sq [μm] for the aluminium alloy AW-5754 surface from a selected measuring area as a function of the feed rate v_f

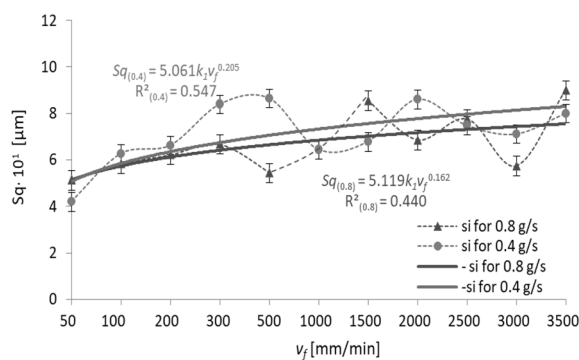


Fig. 15 Graph of changes in the mean value of the roughness parameter Sq [μm] for the silicone surface from a selected measuring area as a function of the feed rate v_f

The analysis of changes in the skewness coefficient Ssk [μm] (Skewness of selected) and kurtosis Sku [μm] (Sku Kurtosis of selected area) is presented in Fig. 16-22.

Ssk is the surface asymmetry coefficient, i.e. – the coefficient of skewness of the topography height distribution (ordinates) of the surface, while Sku is the surface inclination coefficient Sku (excess or kurtosis), i.e. the coefficient of topography height (ordinates) distribution concentration of the surface. Both of these coefficients describe the surface from an operational point of view. Their graphic interpretation can be presented as in Fig. 16. The stronger the negative value of the skewness coefficient Ssk , the more strongly the vertices of irregularities are flattened. In the case of kurtosis, the more positive the value of the Sku coefficient ($Sku > 3$), the sharper vertices of surface irregularities are, and vice versa, the lower the value of this coefficient ($Sku < 3$), the more "rounded" the vertices are. Figure 16 presents a geometric interpretation that helps understand the consequences of changes in both indicators.

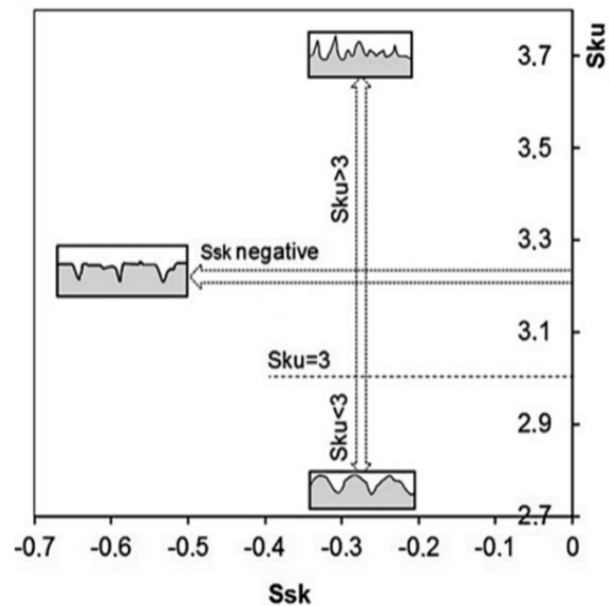


Fig. 16 Geometric interpretation using the skewness coefficient Ssk of the topography height (ordinates) distribution of the surface Ssk , and of the surface inclination coefficient Sku (excess or kurtosis)

Based on the conducted experimental research, it can be concluded that above the terminal feed speed $v_f = 500$ mm/min – regardless of the abrasive mass expenditure (ma : 0.4, 0.8 g/s) for the interphase zone – at the aluminium alloy AW-5754 – the silicon boundary, the Ssk coefficient assumes negative values, which means that surface irregularities in this area have a flattened form, favourable from the operational point of view (Fig. 17). The reverse phenomenon was observed for the aluminium alloy surface, where the negative values of the skewness coefficient Ssk were determined in the range of low feed rates v_f to 2000 mm/min (Fig. 18). For silicone, in practically the entire tested range of feed rate variability, the skewness of Ssk assumed positive values and decreased with the feed rate increase. This means that due to its material properties, the surface of the silicone due to its high susceptibility to decomposition at high kinetic energy of the water-abrasive stream has sharp vertices of irregularity changing the shape towards the flattened as the feed rate increases. Similarly to the above, no significant impact of abrasive expenditure on the values of the analysed Ssk coefficient was observed. The low value of derivative coefficients in all analysed cases of changes in the Ssk coefficient in relation to the considered surfaces of materials constituting the interlayer structure indicates a low quality of the assumed linear model. However, the assumption of a polynomial model for the such registered experimental data remains doubtful, despite better results related to the determination coefficient.

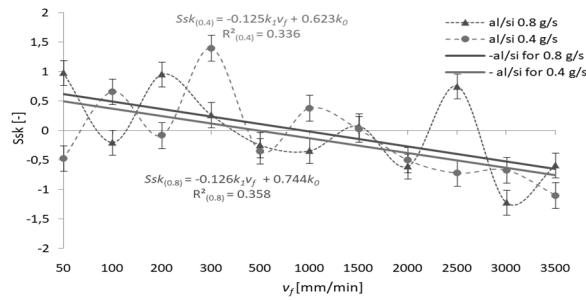


Fig. 17 Graph of changes in the roughness profile skewness of the Ssk interphase surface [-] at the aluminium alloy AW-5754 – silicon boundary, from a selected measuring area as a function of the feed rate v_f (Skewness Ssk [-] of selected area)

In the case of the Sku coefficient, its highest values were observed for silicone (on average 12-14). They are higher by 20% in relation to the coefficient of the registered roughness profile Sku [-] of the interphase surface at the aluminium alloy AW-5754 – silicone boundary (10-12). The lowest average Sku values were recorded for the cutting surface of the aluminium alloy AW-5754 alone ($Sku=6-8$). The results of these tests are presented in Fig. 20-22. It should also be noted that significant – high peak values of this coefficient ($Sku=3-18$) indicate that, especially for silicone, the irregularity peaks are very sharp and pointed (the Sku peak value reaches up to 18).

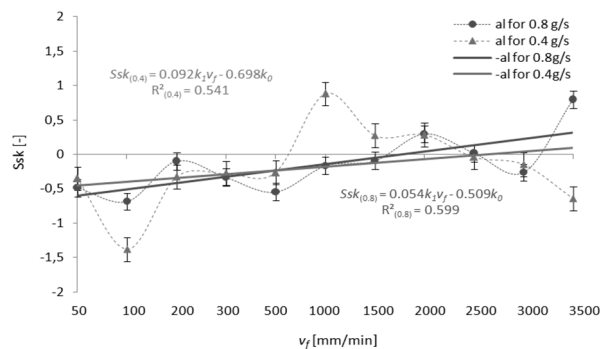


Fig. 18 Diagram of changes in the surface roughness profile skewness Ssk [-] of the aluminium alloy AW-5754 from a selected measuring area as a function of the feed rate v_f

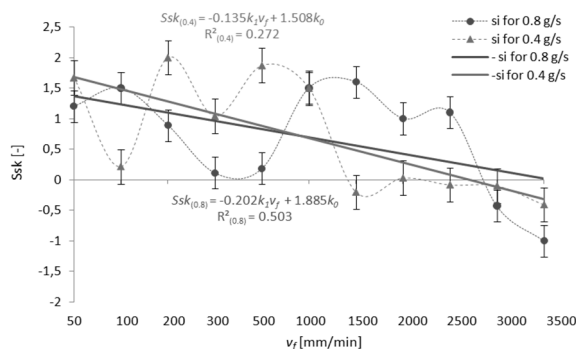


Fig. 19 Diagram of changes in the surface roughness profile skewness Ssk [-] of silicone from a selected measuring area as a function of the feed rate v_f

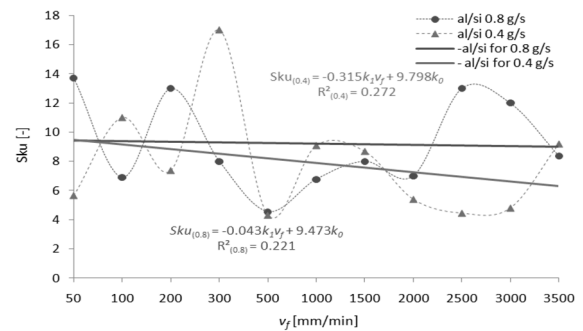


Fig. 20 Graph of changes to the Sku [-] kurtosis coefficient of the interphase surface roughness profile at the aluminium alloy AW-5754 – silicon boundary, from a selected measurement area as a function of the feed rate v_f

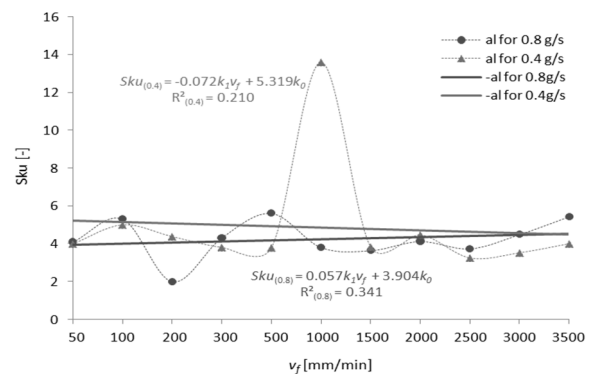


Fig. 21 Graph of changes in the Sku coefficient [-] of kurtosis of the roughness profile of the aluminium alloy cutting surface AW-5754, from the selected measuring area as a function of the speed of the feed motion v_f

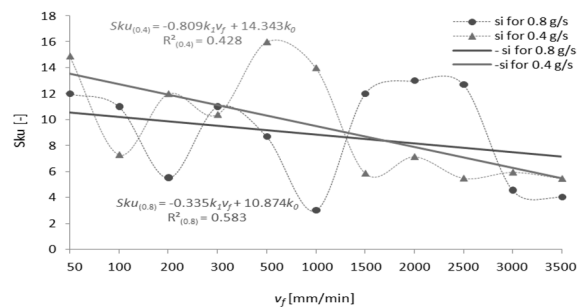


Fig. 22 Graph of changes in the Sku [-] kurtosis coefficient of the silicone cut surface roughness profile, from a selected measuring area as a function of the feed rate v_f

The conducted tests also show that the surface roughness obtained with the use of AWJ is largely determined by the cutting process parameters as well as the mass expenditure of the abrasive in the hydro-abrasive stream. It is worth noting that not every analysed roughness parameter and coefficient is determined by the influence of technological cutting conditions in the same way. This depends to a large extent on the properties of the component materials of the cut, multilayer composite structure, their susceptibility to machining, hardness

and geometrical features (thickness).

It should be noted that the factors impacting the results of the geometric structure constitution of multi-layered hybrid compositions remain in mutual interactions with one another, therefore such studies require optimization. The position of the multilayer structure in relation to the water-abrasive stream and the order of cutting particular layers of the multilayer composition are also of key importance.

4 Summary and conclusions

In this paper, the cutting process of the combined structure was carried out and its post-cutting parameters were studied. According to the presented experimental results, the mechanisms of interfacial interactions are complex, and their visual study requires careful analysis. Their effects on the roughness parameters were studied in detail. The geometric features of the interfacial structure of silicone vulcanized joints have not been analyzed in the world literature so far. The presented research is an important supplement to the knowledge in this field. During the tests, the highest-class scientific and research equipment was used. A practical example of the application of the materials studied and described in the article are the instrumentation parts of a food packaging line. Appropriate preparation of such parts by means of AWJ processing will speed up the process of their manufacture, for example, by eliminating finishing operations.

Based on the obtained results, the following conclusions have been formulated:

- The aluminium alloy AW-5754 – silicone multilayer structure can be effectively cut with AWJ hydro-abrasive processing while maintaining a relatively high cut surface quality. The application of this type of machining have a practical dimension. Such structures are used in industry for the preparation of tooling for the construction of equipment in the preparation of food packaging processes.
- The choice of appropriate cutting technological parameters has a significant impact on the cut surface quality of composite multilayer structures. In the case of cutting with feed rates up to 500 mm/min, lower values of roughness parameters are clearly visible.
- In the range of low feed rate values during the cutting process, the spatial parameters of surface roughness S_q and S_a are similar for different materials of the cut multilayer structure. The nature of parameter changes is non-linear. The approximation of results by an exponential function allows to construct a relatively high quality model of the process.
- At low feed rate values, the values of the analysed roughness parameters at different heights differ only slightly from one another. The value of roughness in the lower part of the material being cut in the middle and upper part takes similar values. It should be noted that by maintaining a similar value of roughness at the entire height, the surface obtains a homogeneous structure, which has a positive effect on its operation
- A slight reduction in the feed rate v_f for compositions of the same thickness (same material and thickness of silicone and aluminium alloy AW-5754) reduces the roughness value and thus improves the surface quality.
- Based on the curves of roughness parameter (S_a , S_q) changes, it is possible to determine the non-linear nature of changes and the increase in roughness along with the feed rate v_f .
- The change in the abrasive material expenditure has a non-linear effect on the values of roughness parameters (S_a , S_q) and coefficients (Ssk , Sku). These parameters determine the wear process. Maintaining the values of the parameters close to zero significantly increases the service life of the operated surface.
- The analysis of the presented images of surface irregularity distribution confirmed by the characteristics of changes in the feed rate function v_f , indicates a significant impact of the mass flow rate m_a on the geometric structure of the analysed surfaces and only a slight impact on changes in surface in the interphase zone at the aluminium alloy AW-5754 – silicone phase boundary (A/B), and significant differences in irregularity on the surface of silicone A and the aluminium alloy B.
- Excessive abrasive material expenditure during processing should be avoided. This may cause adverse changes in surface roughness. By also using a lower abrasive expenditure, we reduce the cost of the process.
- Factors influencing the results of the geometric structure constitution of multilayer

hybrid compositions remain in mutual interactions with one another, therefore such studies require optimization.

- Properly prepared surface after cutting will eliminate the use of subsequent finishing treatments such as milling. This lowers the cost of preparing the parts to be made and speeds up the time for their manufacture.

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