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Selection of the Parameters of Abrasive Water Jet Cutting on the Delamination in Carbon Laminates

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STRESZCZENIE: The paper presents an analysis of the influence of abrasive water jet cutting parameters on the delamination of carbon laminates. As such materials very often require preliminary processing in the form of cutting, abrasive water jet cutting is widely used. A polymer composite made of thermosetting epoxy resin reinforced with carbon fiber (CFRP) was tested. The tests were carried out on an Eckert Combo portal cutting machine, designed for thermal cutting and water jet cutting with the addition of abrasive. Based on the results obtained, it was found that the change in the thickness of the laminate at the initial point of cutting with a water-abrasive jet depends on the adopted value of the jet's working pressure and the abrasive flow rate. Moreover, it was noticed that with the appropriate selection of process parameters, it was possible to reduce the occurrence of delamination.

SŁOWA KLUCZOWE: delamination, carbon laminates, abrasive water jet cutting, composite

1. Introduction

Due to the diversity and complex mechanical properties of engineering materials [1], their processing is demanding and thus requires the use of various machining techniques [2]. The high quality requirements for structural components imply careful selection of tools and machining parameters [3,4]. Manufacturing processes that are used for cutting engineering materials include gas cutting, laser beam cutting, electrical discharge machining, as well as water jet cutting and abrasive water jet cutting (known as hydro-abrasive cutting).

2. Abrasive water jet cutting

Abrasive water jet (AWJ) cutting is a manufacturing process that uses high-pressure jets of water with abrasive particles to cut various types of materials [5]. Delivered by a pressurizing pump, a stream of water passes through a mixing tube where it creates negative pressure and draws in the abrasive material. As the water stream and the abrasive material pass through the mixing tube and nozzle, the water jet is mixed and accelerated. The mixture of water and abrasive hits the surface of the material being cut, and the abrasive particles with high kinetic energy cause an initial crack in the workpiece, while the water removes the separated material [6][5].

When used in conjunction with the abrasive, the water stream does not require an additional direct contact between the cutting tool and the material generating its wear. In AWJ cutting, the edges of the materials being cut do not undergo thermal deformation, nor are subject to structural changes due to high temperature as the temperature at the point of material separation does not exceed 40°C [1,3]. This is a major advantage of AWJ over other cutting methods such as laser or plasma cutting. AWJ can be used to cut various types of materials, which provides the operator with high degree of processing versatility [1,7]. This is especially important when cutting hard and abrasive materials.

The selection of AWJ technique for a particular application depends not only on the assumed cutting speed, desired edge quality and material thickness, but also on the properties of the material being cut. A failure mode associated with AWJ is delamination of the material being cut. Delamination can occur when cutting materials that are adhesive-bonded or composed of materials with different properties (as is the case with composite materials).

3. Research method

The study was conducted on samples of a thermoset epoxy resin polymer composite reinforced with carbon fibres (CFRP). The fibres had an alternate layup in a rectangular arrangement (0/90). The test materials were produced by autoclaving. Flat composite plates were made of non-autoclaved prepreg (fabric). They were autoclave-heated at 120ºC first and then at 180ºC. The Scholz 300 autoclave was used for curing.

Experiments were conducted on Eckert's WaterJet Combo portal cutting machine designed for thermal cutting and abrasive water jet cutting. The Combo cutting machines are CNC machines for cutting sheet metal and are originally provided with cutters such as waterjet cutting heads, abrasive waterjet cutting heads and plasma torches.

WaterJet Combo device can be used for both straight and curved cutting. This cutting machine is equipped with a state-of-the-art CNC ECK 872 controller running on Windows XP that is connected to a touch display. This solution improves the interaction between the machine and the operator. An Ethernet connection and USB interface allow the transfer of previously prepared programs. It is worth noting that the WaterJet Combo cutting machine is equipped with an UHDE high-pressure pump that can generate a maximum pressure of 350 MPa, which makes it possible to cut materials cut with thicknesses of up to 150 mm.

4. Resolults

The results of this study, which involved performing AWJ tests on Eckert's WaterJet COMBO portal cutting machine using variable operating pressure, followed by subsequent microscopic measurements, were subjected to close analysed. The results were analysed with respect to laminate thickness before and after AWJ, at the starting point of the cut where the delamination of the composite sample occurred. The prepared composite material removed from the autoclave had a thickness of 5 mm.

Below are given examples of photographs showing the cross sections of the laminates after the cutting process conducted with variable operating pressure. An analysis of the photographs reveals the presence of delamination in different regions of the material. In Fig. 4a the delamination can be observed in the upper layer of the material. In Fig. 4b one can observe a separation of the upper layer of the material. In the last figure (Fig. 4c), the delamination occurs over the entire cross section of the composite material.

The study investigating the effect of the parameters of AWJ on the delamination in carbon laminates involved modifications in the parameters of the cutting process itself. The following were maintained constant: abrasive material type, piercing time [s], piercing speed [mm/min], and radius of a circle at piercing [mm], while operating pressure [bar] was variable. The presence of internal defects in the laminate was assumed to be a disturbing factor. The thickness of the composite material at the starting point of the cut was taken as an output factor.

a)

b)

c)

Fig. 1. Examples of photographs showing the laminate section after AWJ conducted with the following operating pressures: a) 1500 bar, b) 2500 bar c) 3500 bar

5. Conclusion

The numerous applications of composite materials and their processing raise expectations regarding continuous enhancement of their performance and efficiency. Therefore, it becomes obvious to strive to eliminate phenomena and processes that could affect the reliability of obtained components. Given the possibility of creating polymer composites with non-linear characteristics, it is recommended that research be conducted on these materials. Results of such empirical studies can then be used to create advanced mathematical models describing resulting relationships.

The results have shown that the change in the thickness of the laminate at the starting point of the cut depends on the operating pressure. However, it has been observed that the selection of an appropriate pressure value makes it possible to reduce the occurrence of delamination. The attempt made in this study to describe the relationship between pressure and delamination can serve as a basis for optimization of AWJ parameters and prediction of laminate thickness at the starting point of the cut. This approach may further affect the selection of a cutting strategy.

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