Experimental study on reverse engineering in case of composite materials cut by water jet cutting

Ioan Alexandru Popan [*], *Nicolae* Balc, *Alina* Popan and *Alexandru* Carean

Technical University of Cluj-Napoca, B-dul. Muncii, No. 103-105, Cluj-Napoca, Romania

Abstract. The main objective of the paper consists in remanufacturing of a part, through Abrasive Water Jet Cutting, using a method of reverse engineering based on 3D scanning. The characteristics of this process, the equipment and the main applications are presented. The research starts with manufacturing of a master model made by CFRP. This master model is a complex part cut by abrasive water jet cutting. In scanning process was used the 3D Scanner Artec Space Spider and the point cloud was processed using Artec Studio 11 software. By using this new 3D model was manufactured a new part, with the same setup. The quality characteristics (accuracy and surface quality) of this part was compared with the master model. The paper presents the advantages and disadvantages of this reverse engineering method applied on abrasive water jet cutting process.

1 Introduction

Composite materials such as Carbon Fiber Reinforced Plastics (CFRP) are an innovative solution for many applications in aerospace industry, automotive industry, medical devices, marine goods, etc. [1].

CFRP materials are wide used in industrial application because of their properties: high strength to weight ratio, corrosion resistance, electrical conductivity fatigue resistance, low coefficient of thermal expansion etc. [2].

Abrasive water jet cutting (AWJC) uses a pressurized water jet at a very high pressure and abrasive particles. The high-pressure jet is designed to transmit the kinetic energy of abrasive grains. The main advantage of this process is that, it is a solution for cutting all kind of materials: aluminum, stainless-steel, steel, titanium alloy, composites or even ceramics [3, 4].

Processing CFRP through AWJC has major advantages: small cutting forces, low tool wear, no thermal distortion, low mechanical loading and good surface integrity and quality [5].

To analyze the surface quality of the parts made by CFRP processed using AWJC the surface parameters are measured in three zones: initial damage zone, smooth cutting zone and rough cutting zone (figure 1) [2, 6, 7].

[*] Corresponding author: ioan.popan@tcm.utcluj.ro

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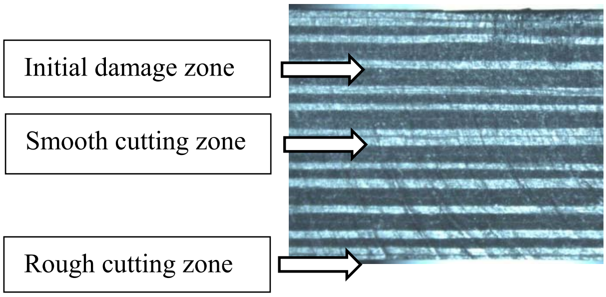

Fig. 1. The main zones of a surface cut by AWJC [2].

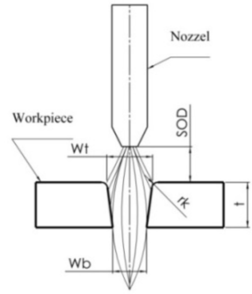

Fig. 2. The kerf geometry [2].

When is analyzed the dimensional accuracy, the kerf geometry (figure 2) and the part contour is measured [2, 8].

In industrial applications is often meet necessity of remanufacturing complex parts made by CFRP [9]. By this reason reverse engineering is a solution in this case. The aim of the reverse engineering (RE) is the digital reproduction of an existing part.

The paper presents an experimental study on remanufacturing a complex part of CFRP, using abrasive water jet cutting.

2 Experimental procedure

2.1 The master model

First step in this experimental study was to design and manufacture a master model. The 3D part made for this study is presented in figure 3.

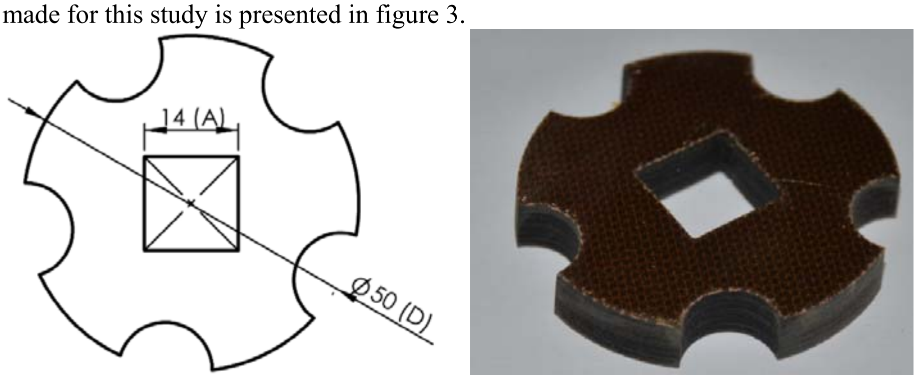

Fig. 3. The master model.

Experiment was carried out on an abrasive waterjet cutting machine Omax 2626 (figure 4), using a CFRP composite material. It has a high pressure pump 400 MPa and the maximum feed rate is 4500 mm/min.

The workpiece had the dimensions: 60 x 400 x 6 mm and it was fixed in the clamping system presented in figure 5.

Values of process parameters, used on this study, are shown in Table 1. This combination of the process parameters is recommended by Omax, in order to obtain the best dimensional accuracy for this application.

Fig. 4. The water jet machine Omax 2626.

Fig. 5. The clamping system.

Table 1. Process parameters used in the experiments.

Technological parameter	Value
Sample thickness	6 mm
Pressure	355 MPa
Feed rate	100 mm/min
Abrasive type / size	Australian Garnet / 80 mesh
Abrasive mass flow	0.440 kg/min
Nozzle diameter	0.76 mm
Orifice diameter (diamond)	0.35 mm
Standoff distance	2 mm

The material used in this analysis is a plate consisting of multi-layer carbon fiber reinforced plastics (CFRP). The material is made from carbon fiber prepreg (CE 8201-200-45, 3k-fabric style 452 in twill weave 2/2) with an epoxy resin (364 g/m²) in a heat pressing process.

2.2 The 3D scanning

The geometry of the part was obtained using the 3D Scanner Artec Space Spider. This is a high-resolution 3D scanner based on blue light technology. It is recommended for scanning small objects or intricate details of large industrial objects at high resolution (3D point accuracy: 0.05 mm) in a short time (scanning speed: 7.5 fps). The scanner was handled by hand from around 35 mm distance from the model. The scanning process and the cloud point are illustrated in figure 6.

Fig. 6. The scanning process and the cloud point.

To obtain the reconstructed model the cloud point was converted in a 3D surface using Delaunay triangulation [10-11]. The cloud point was processed using Artec Studio 11 software. CATIA software was used to correct the scanning errors. In figure 7 is presented the final 3D surface obtain from scanning process.

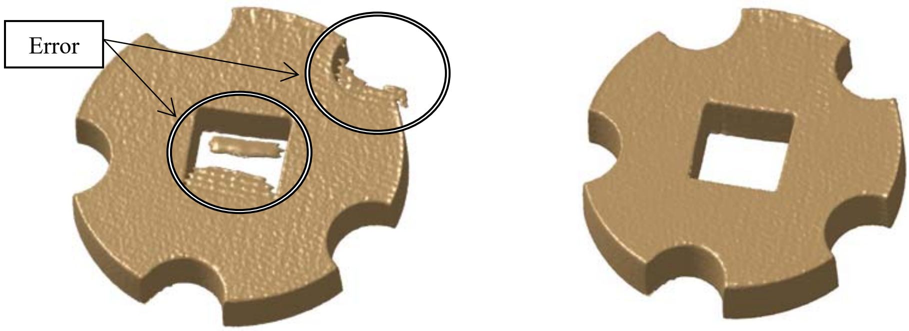

Fig. 7. The 3D surface whit errors and the final 3D surface.

For remanufacturing this composite part through abrasive water jet cutting is necessary to generate a 2D cutting sketch. To generate this 2D sketch the 3D surface was cut with a plan. The 2D cutting sketch is illustrated in figure 8.

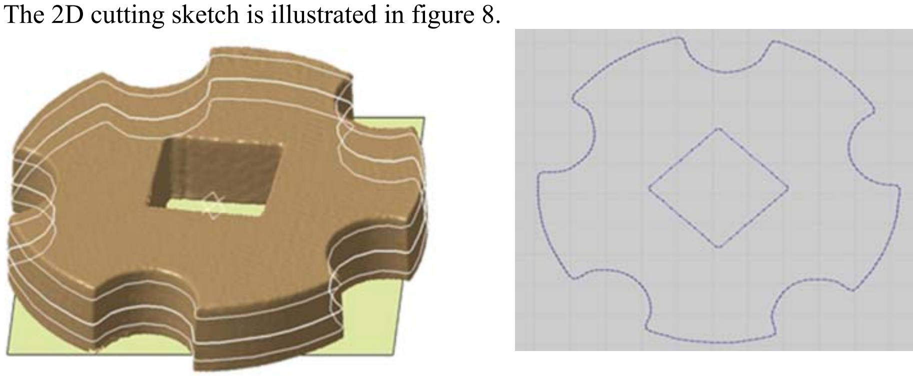

Fig. 8. The 2D cutting sketch obtained by cut the 3D surface.

2.3 Remanufacturing of the part

To analyze the accuracy of the reverse engineering process, a new part was manufactured. This part was made using the 2D sketch, obtained by cutting the 3D surface. For comparing this part with the master model, the same process parameters were used and the same CFRP material. In figure 9 is presented the new part.

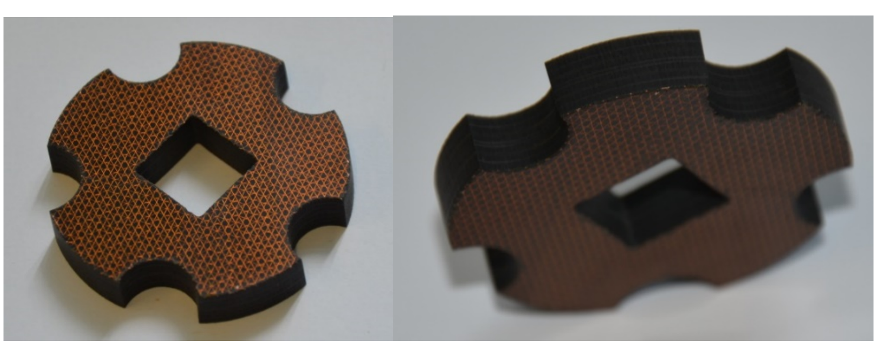

Fig. 9. The new part obtained using reverse engineering method.

3 Results and discussions

3.1 Surface quality analysis

To evaluate the efficiency of this reverse engineering method applied in case of parts made by abrasive water jet cutting the cut surface quality was analyzed. The surface cut by AWJC was measure in three different zones: initial damage zone (1 mm under the top of the surface), smooth cutting zone (in the middle of the surface) and rough cutting zone (1 mm over the bottom of the surface).

The roughness was measured using a Surface Roughness Measuring System SURFTEST SJ-210 from Mitutoyo. The values obtained are presented in the Table 2.

Table 2. Surface roughness.

	Master model	Reconstructed model
The initial damaged zone Ra, μm	5.2	6.5
Smooth zone Ra, μm	3.5	5.3
Striation zone Ra, μm	7,2	10.5

As the table shows, the biggest values of the surface roughness were obtained in the case of part made through reverse engineering method (Ra 10.5 μm). In the case of parts made using water jet cutting process, the surface roughness increases from the top to the bottom of the cut surface (from 5.2 up to 7.2 μm for master model and for reconstructed model from 6.5 up to 10.5 μm reconstructed model). In industrial application when the surface quality is evaluated, the biggest value is analyzed.

The difference between the roughness of the master model (7.2 μm) and the roughness obtained in case of the reconstructed model (10.5 μm) is 3.3 μm. In conclusion, the surface roughness is increasing up to 45% in case of reconstructed model through abrasive water jet cutting.

3.2 Dimensional accuracy analysis

Dimensional accuracy was measured using a microscope, type PG 2000. The kerf geometry is: a cutting angle error of 0.04 mm, taper angle 0.73° and the top edge radius of 0.2 mm. The kerf geometry is the same for the both parts, this geometry depends by process parameters.

To find out which of the accuracy of this method, two dimensions A and D were analyzed. The dimensions and deviations obtained are presented in Table 3.

Table 3. Dimensional accuracy.

Dimensions	CAD model	Master model	Reconstructed model
D, mm	50	50.02	50.17
Deviation, mm		+0.02	+0.17
A, mm	14	14.03	14.13
Deviation, mm		+0.03	+0.13

Analyzing the external diameter D, a value of 50.02 mm was measured in case of master model and 50.17 mm for the reconstructed model. The deviation between master model and reconstructed model is +0.15 mm, approximate 0.3%.

In the case of internal dimension, A, the reconstructed model has a deviation of 0.1 mm, approximate 0.8%.

4 Conclusions

The paper presents an experimental study on remanufacturing a complex part of carbon fiber reinforced composite materials, using abrasive water jet cutting.
The reverse engineering is a useful tool in remanufacturing complex parts made by CFRP because of their complexity. Without a 3D model or a 2D sketch it is almost impossible to remanufacture at a good accuracy a complex part. For this reason, 3D scanning could be a good solution for this type of applications.

First step in this experimental study was to manufacture using abrasive water jet cutting a 3D master model from CPRF. This master model was scanned using a precise scanner, type Artec Space Spider. The cloud point was processed to obtain the 3D surface using Artec Studio 11 software. To obtain the 3D cutting sketch the 3D surface was cut with a plan. To analyze the accuracy of this reverse engineering method the remanufactured model was cut using abrasive water jet cutting using the same parameters as the master model.

The deviation between master model and reconstructed model in case of external dimension is +0.15 mm, approximate 0.3%. In the case of internal dimension, the reconstructed model has a deviation of 0.1 mm, approximate 0.8%.

Analyzing the surface quality, the difference between the roughness of the master model (7.2 μm) and the roughness obtained in the case of the reconstructed model (10.5 μm) is 3.3 μm.

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