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Rheonomic phenomenon shrinkage of holes drilled in fibreglass and carbon fibre-reinforced polymer composites

Aleksandr Dudarev*, Konstantin Volegov and Georgiy Kurzanov

Abstract

Background: The research is devoted to machining polymer composite materials and reflects a non-trivial, accuracy-affecting phenomenon that occurs while drilling polymer composite materials, i.e. reduction of holes diameter over time after processing.

Methods: The article contains experimental data obtained in the research of rheonomic shrinkage of holes after drilling various grades of polymer composite materials. The research involved using different types of tools (high-performance Ham solid carbide drill bits and diamond drill bits). The tests were carried out combining different parameters of drilling modes. We adopted the range of spindle speed change n = 10,000-20,000 rev/min and tool feed range S_m = 50-300 mm/min. Measurements of shrinkage were performed with the help of ATOS III Triple Scan XL scanning system immediately after treatment and in 48 h thereafter. Based on the scanned polygonal mesh of each hole, three-dimensional models of holes drilled in the samples were built. Then, these models were verified against nominal drillings using GOM Inspect software. In this way, the values of rheonomic shrinkage were obtained. Verification was carried out according to Gaussian method of measurements by coincidence using variation variables sigma (Gaussian best-fit 3 sigma).

Results: Shrinkage of holes does not take place in structural materials. However, in polymer composite materials, shrinkage of the drilled hole of 10 mm nominal diameter may reach reduction in diameter of 0.02-0.03 mm during a period of 48 h and depends on the grade of the polymer composite material. Observations have shown that shrinkage also depends on machining mode parameters.

Conclusions: We have developed two hypotheses to explain the influence of processing mode parameters on rheonomic shrinkage: the first one relates to the rate of processing, the second – to the force factors.

Keywords: Drilling, Hole, Polymer composite, Shrinkage, Polygonal mesh

Background

Polymer composite materials have found very wide application in the aerospace industry, shipbuilding, and power-plant engineering.

Multifold increase in manufacturing the products from polymer composite materials requires a corresponding growth in the volume of machining, which is a time consuming and specific process. The most common machining operations in the technological cycle of manufacturing the products made of polymer composite materials are milling, drilling, and grinding Dudarev (2009).

The quality of the products made of polymer composite materials after mechanical processing largely depends on the physical and mechanical properties of the work piece, cutting conditions, geometric parameters of the cutting part of the tool, tool material, cutting tool wear, etc. Dudarev (2009).

Fibreglass, carbon fibre-reinforced polymer and many other polymer composite materials are viscoelastic materials. Therefore, in the process of machining thereof, residual plastic deformation is observed, which depends on

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various factors. Elastic rheonomic recovery of the processed surfaces affects the accuracy of processing.

The scientists, as well as researchers of materials with shape memory, have been studying the rheonomic phenomenon of recovery taking place in polymer composite materials. Their research is represented in publications by Raghavan et al. (2010); Oshaughnessy and Vavylonis (2003).

Designers and technologists of machine-building enterprises need the data on the values of shrinkage of holes in polymer composite materials. Knowing shrinkage values in polymer composite materials allows them to account for possible change in the dimensions of holes for fastening elements while designing heavy-duty products of rocket and spacecraft engineering, aviation, and shipbuilding made of polymer composite materials.

Review

Shrinkage phenomenon in holes is difficult to simulate adequately, thus experimentally based empirical research is still relevant. In this paper, we give empirical dependence data intended for determination of the amount of shrinkage obtained by different researchers in the course of multi-factor experiments.

When drilling holes in polymer composite materials, the diameter of the drilled hole is smaller than the diameter of the cutting tool. Such observations were for the first time made by the researchers of plastics machining as stipulated in Stepanov (1987); Drozhzhin (1983); Krishtopa et al. (1980).

According to Shtuchnyi (1974), the reasons for the reduction in hole diameter are high elasticity of polymer composite materials, residual internal stresses, humidity of the environment, etc. Similar effect was observed by the scientists and described in publications by Krishnamoorthy et al. (2009); Miller (2014); Dae-Wook Kim (2002); Asamoah and Wood (1972); Davim et al. (2007); Shokrieh and Kamali (2005).

It is interesting to note that various researchers suggest different approaches to the determination of the amount of shrinkage. Thus, Krishtopa et al. (1980) and Stepanov (1987) point out the elastic recovery of polymer composite materials after processing and suggest the formula initially developed by Drozhzhin (1983) and given in the paper for the determination of the elastic recovery of the processed surface of laminated plastics (getinaks, textolite - PCB) after cutting with a non-worn tool. The formula suggested by Drozhzhin (1983) contains the following factors: drill bit cutting edges rounding radius, tool cutting wedge angle of processed surface in contact with the rear surface of the tool, tool clearance angle, ratio, taking into account the processed material and stiffness of the system machine-adaptation-tool-work piece. However, the formula given in Drozhzhin (1983) is designed for determination of the shrinkage in laminated plastics and is not acceptable for the calculation of the shrinkage in polymer composite materials.

Another researcher Shtuchnyi (1974) presented data on the reduction in the hole diameter as compared with the drill diameter by 0.03 ... 0.1 mm (immediately after drilling), and further reduction in the holes diameter of 0.01 ... 0.05 mm occurs during following 24 h, after which the diameter does not change. Shtuchnyi B.P. suggest an empirical expression for the calculation of the shrinkage in the details made of electrical insulating materials, such as textolite - PCB, which in their structure are similar to polymer composite materials (mm):

$$\Delta d = 0.32 \cdot v^{0.62} \cdot S^{1.54} \quad (1)$$

where v – cutting speed, m/s; S– feed rate, mm/rev.

According to the expression (1), the amount of holes shrinkage is affected by the parameters of drilling mode (cutting speed and feed rate). However, using the expression (1) is not adequate for the evaluation of shrinkage in polymer composites, as they represent another class of processed materials.

Since experiment is the most reliable method for the determination of these amounts of hole shrinkage in polymer composite materials, we have held a multi-factor experiment to determine shrinkage following drilling of D10 ($^{+0.100}_{+0.040}$) mm holes using two types of cutting tools for three different grades of polymer composite materials.

In order to estimate the impact of drilling mode parameters and tool type on the amount of holes shrinkage in polymer composite materials (carbon fibre and fibreglass of various grades) experimental studies have been carried out in the "Centre for High-Tech Engineering Industries" of Perm National Research Polytechnic University (PNRPU, Perm, Russia).

Methods

The research involved samples of polymer composite materials (plate size 150 mm × 200 mm) of the following grades: carbon fibre mark VKU-39 (reinforced of brand Porcher fibres), thickness 3 mm; carbon fibre mark KMU-4E, thickness 5 mm; fibreglass mark VPS-33, thickness 5 mm.

Experiments consisted in drilling holes Ø10 D10 ($^{+0.100}_{+0.040}$) mm whereas the error was taken into account by accuracy tolerance. We used two types of tools: diamond drill diameter D = 10 ($^{+0.100}_{+0.050}$) mm, diamond layer grain size 125/100 μm, diamonds grade AC 32, coating applied by electroplating on nickel binding from works of Dudarev (2012, 2014) (Fig. 1); and Ham Precision series 380 (Germany) carbide drills D = 10 ($^{+0.07}_{+0.020}$) mm, apex angle (in plan top view) 2ϕ = 163°, front angle γ = 12°, clearance angle α = 20°, the angle of helical grooves inclination ω = 25° (Fig. 2).

Fig. 1 Diamond drill

When selecting drilling modes, we used own data obtained in extensive experimental studies Dudarev et al. (2014) and ensuring high quality of processed holes. The spindle rotation frequency was assumed n = 10,000-20,000 rpm and tool feed rate range was assumed S_m = 50-300 mm/min (Table 1).

Drilling was performed using three-axis milling and engraving machines FlexiCAM XL 1525 NBM PRO (working area 2580 mm × 1540 mm × 280 mm) (Fig. 3). To control the machine FlexiCAM XL 1525 NBM PRO, we developed a programme in ArtCAM environment. Machine spindle allows the speed up to 24,000 rev/min.

Experiments at each combination n and S_m were conducted three times. Replacement of cutting tools both, diamond drills and carbide drills was performed based on the technological criteria of bluntness. An obvious manifestation of the technological criteria were signs of abnormal operation, requiring a tool change due to deterioration quality of processed holes (cut-away, formation around the hole circumference). The drilling process was recorded with JVC video camera and Sony Cyber-shot DSC-S780 camera, which imaging is shown in Fig. 4.

Holes measurements were performed using contactless optical measuring system ATOS III Triple Scan XL equipped with photogrammetric system TRITOP Std. model 400 (Germany) with a three-dimensional scanner ATOS III XL (Fig. 5). The scanner operates based on the projection of interference fringes allowing for obtaining work piece points in 3D-coordinates.

Specifications of ATOS III Triple Scan XL: measuring volumes range - 30x24x13 mm to 2.000 × 2.000 × 2.000 mm. resolution – 800.000 to 4.000.000 body surface points per shot, accuracy - 0.004 mm. Certificate of compliance is available for the scanner, metrological verification has been passed. In addition, ATOS III Triple Scan XL optical system comes with a special ceramic template ensuring, scanner self-calibration, which provides metrological reliability and operation of a serviceable measuring instrument.

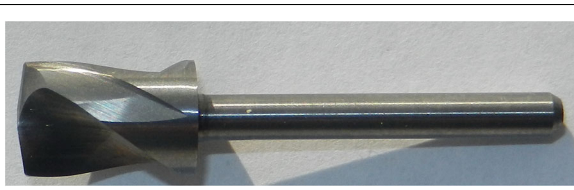

Fig. 2 Ham Precision 380 carbide drill

Table 1 Drilling mode parameters

Mode number	n (rev/min)	S_m(mm/min)
1	10,000	50
2	15,000	75
3	20,000	300

Measurement with ATOS III Triple Scan XL were executed as follows. ATOS III XL scanner was positioned on the sample with drilled holes. After each measurement, the scanner was repositioned in order to scan the sides that were missed during previous scanning. All measurements were automatically converted into a 3D-coordinate system, resulting in the creation of 3D-points cloud. The holes in the samples were measured immediately after drilling and after 48 h. Preliminary experiments showed that major size changes occurred during the first 24 h after drilling, after which the hole sizes do not change. Therefore, to guarantee the measurement stability, we performed second measurement was 48 h past the drilling.

Defects formed at inlet and outlet of the holes in polymer composite materials did not influence diameter measurement process is not affected since the quality of the holes was satisfactory and cloud of points on the inner surface of the hole was scanned. In all cases, to avoid glare, contrast paint was applied to the flat surfaces of the samples.

Polygon mesh generated from the full-scale sample describes the real surfaces rather than the volume, and these surfaces may be of any shape. Surface polygon mesh can be verified by comparison with the data contained in the Computer Aided Design (CAD) packages, CAD utilisation allows for creating ideal geometric elements (circles, cylinders, etc.).

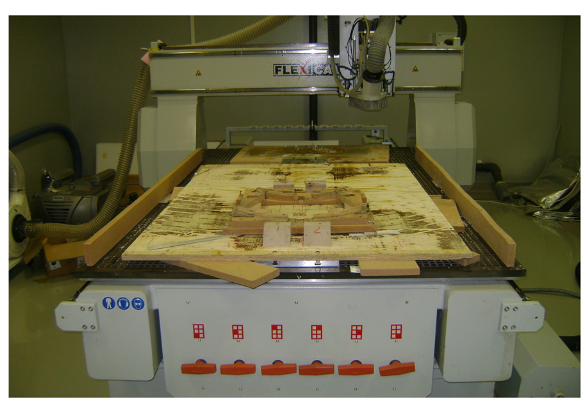

Fig. 3 General view of machine FlexiCAM XL 1525 NBM PRO

Fig. 4 Drilling carbon fibre reinforced polymer KMU-4E with Ham Precision 380 drill

TRITOP system determines coordinates of the reference points on the object, based on which automatic merge of measurement information for different angles is performed with the help of ATOS device. That is why there was a need to apply the reference points onto the samples. This application of reference points of 0.4 mm in diameter on the plate is shown in Fig. 6.

Using GOM ATOS 7.2 included in GOM Inspect software, polygonal meshes obtained with the scanner were analysed, and a digital divergence map was developed.

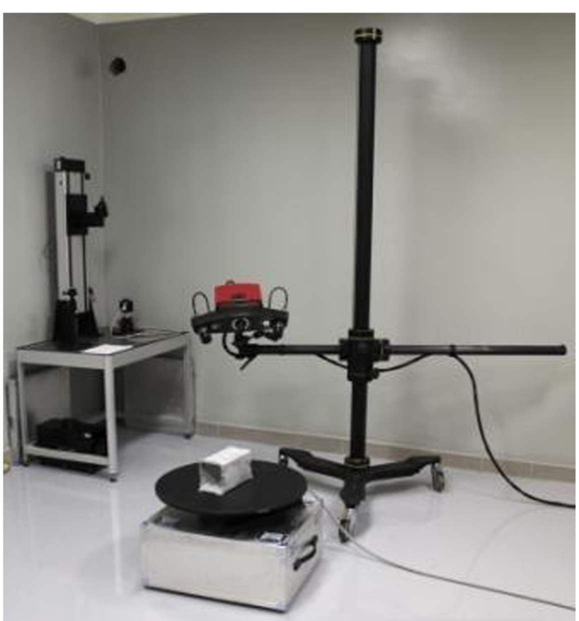

Fig. 5 General view of ATOS III Triple Scan XL installation

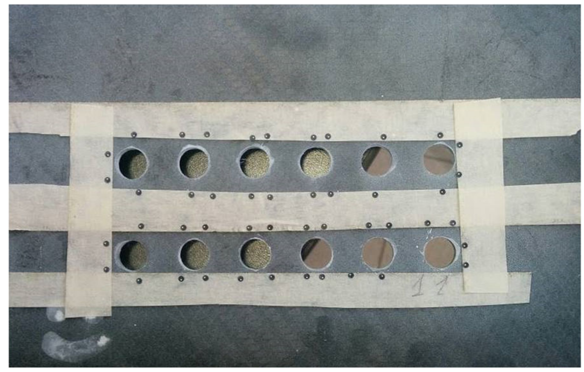

Fig. 6 Reference points on the sample

Based on the scanned polygonal mesh for each hole 3D-models of the holes in the samples were built (Fig. 7).

GOM Inspect enables verification of real scanned objects presented as polygonal meshes with nominal ones. Moreover, GOM Inspect allows for this operation to be done using embedded libraries without importing 3D-objects themselves.

GOM Inspect was utilised to build nominal models of the holes for the comparison purpose. For example, Fig. 8 shows the surface with a nominal radius 5 mm, which is different from the actual measured hole diameter 10.07 mm.

GOM Inspect provides four methods to compare polygonal mesh of the real scanned geometrical form of a cylindrical shape with that of the nominal one built in GOM Inspect. The said methods include:

– Gaussian matching method using variation variable sigma (Gaussian best-fit 3 sigma);
– Chebyshev equations best match method (Chebyshev best-fit); – method the average circumscribed geometry with minimal divergence of the element (Minimum circumscribed element); – method based on the maximum match of the circle curvature as a equidistance of its boundaries from the centre (Maximum inscribed element).

Gaussian matching method was selected as a mathematical equivalent of polygonal meshes for the analysis of the average divergence from the surface (as per GOM Inspect developers′ recommendations).

Thus upon superimposing of the polygonal portions of the measured model on the mathematical model of the hole light and dark (green) colours of the STL grid could be seen (Fig. 8). Darker colour indicates the complete matching of the model actually measured and mathematical models. Lighter colour represents grids mismatch.

This way, real holes sizes results immediately after drilling and after 48 h were obtained.

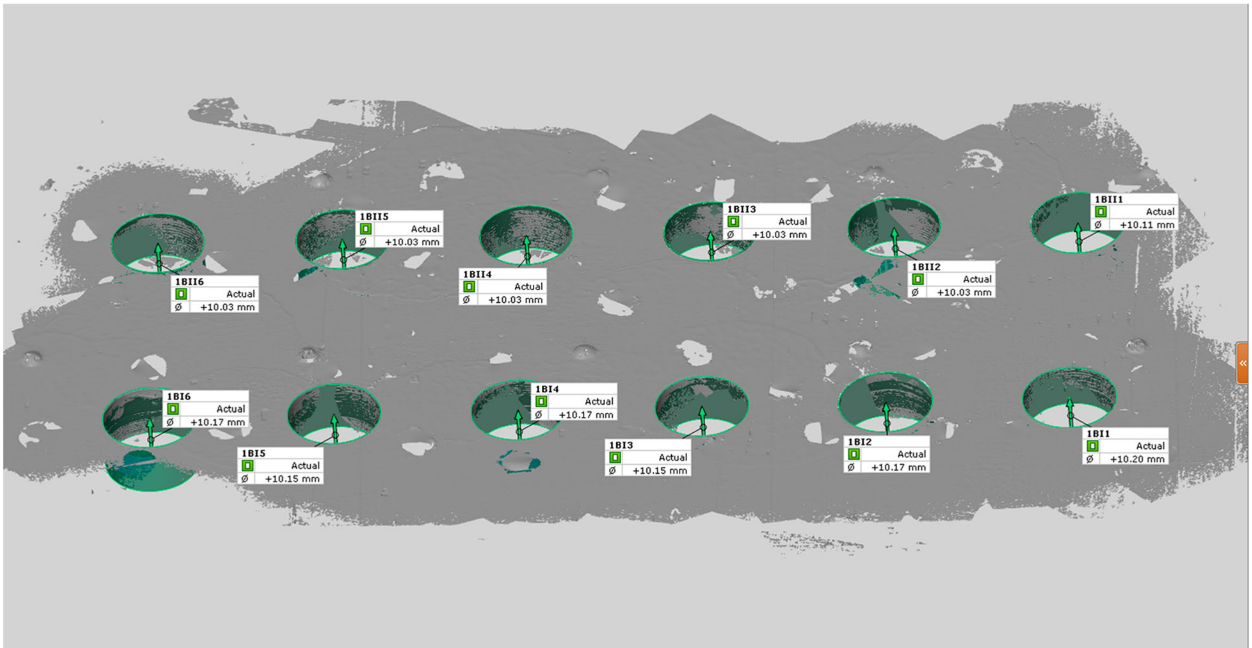

Fig. 7 Polygonal meshes of the holes in the sample

These data acquired in triplicate experiments for each sample and type of the cutting tool, with various combinations of parameters of drilling are listed in Table 2.

Results and discussion

The obtained measurement results (Table 2) were mathematically evaluated in terms of the theory of errors from work of Rumshiskiy (1976).

For the evaluation of the measurement results that dramatically differed from all other results, the methodology provided for in Rumshiskiy (1976), was used in order to validate the feasibility of rejection of “upstart” different values. In our case, the mean square error $\sigma$was unknown prior to the experiments. All measurements were made independently. Let us make use the process of exclusion suggested Rumshiskiy (1976). According to the proposed method it was necessary to compare the output criterion, i.e. the ratio of the absolute value of the difference between the “upstart” different value x_* and the average value $\overline{x}$ of the remaining results and the empirical standard value, with a critical (reference) value of output at a given reliability criterion. In addition, instead of quadratic measurement error σ empirical standard S was used.

Results exclusion condition:

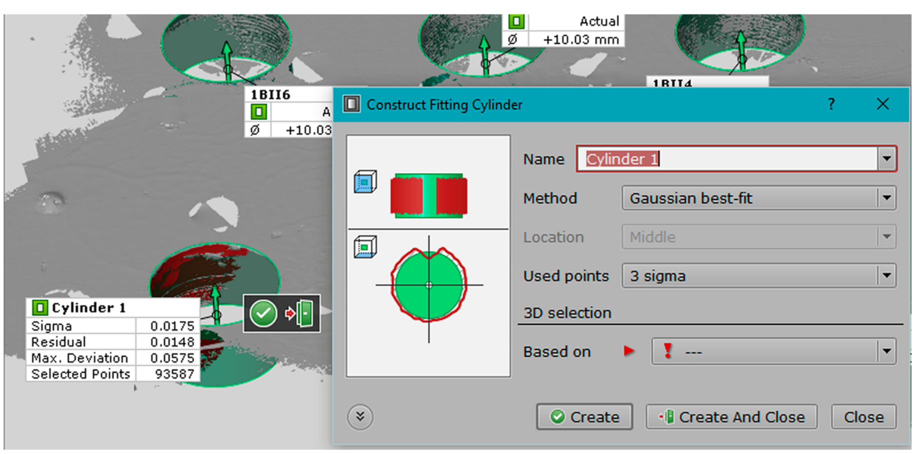

Fig. 8 Matching nominal hole with a real one in the GOM Inspect

Table 2 Diameters of the holes after drilling carbon fiber-reinforced polymers Porcher, KMU-4E and fibreglass VPS-33

Machining mode parameters	Experiment №	Time of measurements	Porcher		KMU-4E		VPS-33	
			Diamond drill	HAM 380 drill	Diamond drill	HAM 380 drill	Diamond drill	HAM 380 drill
S_m = 50 mm/min (S_r = 0.005 mm/rev) *n* = 10,000 rev/min	1	Immediately after drilling	Ø10.08	Ø10.05	Ø10.10	Ø10.07	Ø10.08	Ø10.02
		After 48 h	Ø10.07	Ø10.03	Ø10.09	Ø10.06	Ø10.08	Ø10.02
	2	Immediately after drilling	Ø10.09	Ø10.05	Ø10.89	Ø10.05	Ø10.07	Ø10.03
		After 48 h	Ø10.07	Ø10.04	Ø10.09	Ø10.03	Ø10.07	Ø10.03
	3	Immediately after drilling	Ø10.09	Ø10.05	Ø10.07	Ø10.05	Ø10.07	Ø10.03
		After 48 h	Ø10.08	Ø10.04	Ø10.07	Ø10.04	Ø10.07	Ø10.03
S_m = 75 mm/min (S_r = 0.005 mm/rev) *n* = 15,000 rev/min	1	Immediately after drilling	Ø10.05	Ø10.07	Ø10.07	Ø10.03	Ø10.08	Ø10.03
		After 48 h	Ø10.04	Ø10.06	Ø10.06	Ø10.02	Ø10.08	Ø10.03
	2	Immediately after drilling	Ø10.05	Ø10.07	Ø10.05	Ø10.03	Ø10.08	Ø10.04
		After 48 h	Ø10.03	Ø10.06	Ø10.04	Ø10.02	Ø10.08	Ø10.04
	3	Immediately after drilling	Ø10.05	Ø10.07	Ø10.05	Ø10.04	Ø10.08	Ø10.04
		After 48 h	Ø10.02	Ø10.05	Ø10.05	Ø10.04	Ø10.08	Ø10.04
S_m = 300 mm/min (S_r = 0.015 mm/rev) *n* = 20,000 rev/min	1	Immediately after drilling	Ø10.06	Ø10.04	Ø10.05	Ø10.03	Ø10.06	Ø10.03
		After 48 h	Ø10.03	Ø10.01	Ø10.05	Ø10.02	Ø10.06	Ø10.03
	2	Immediately after drilling	Ø10.06	Ø10.05	Ø10.07	Ø10.03	Ø10.06	Ø10.03
		After 48 h	Ø10.03	Ø10.02	Ø10.05	Ø10.02	Ø10.06	Ø10.03
	3	Immediately after drilling	Ø10.06	Ø10.05	Ø10.07	Ø10.03	Ø10.06	Ø10.03
		After 48 h	Ø10.05	Ø10.03	Ø10.06	Ø10.02	Ø10.06	Ø10.03

$$t > t_n(P) \tag{2}$$

at $$t = \frac{|x_* - \overline{x}|}{S}, \tag{3}$$

where x_* - "upstart" different measurement value, $t_n(P)$– critical reference value at a probable reliability P.

Empirical standard value is defined by the following formula:

$$S = \sqrt{\frac{1}{n_o - 1} \sum_{i=1}^{n_0} (x_i - \overline{x})^2}, \tag{4}$$

where n_o - amount of experiments; x_i - measurements results; $\overline{x}$ - the mean value of the results.

If $t \le t_n(P)$ there is no reason to exclude "upstart" different value.

Assessment of the measurement results for diamond and carbide tools by formula (2) was, made separately for the three different drilling modes. We also took into account the data of holes measurement for each tool after 48 h. A total of six groups of "upstart" different values were evaluated, whereas each group included nine values of diameters (three grades material and three iterations of the experiments).

Evaluation of "upstart" different measurement values immediately after drilling was not performed, because all the values of hole diameters in the column "Immediately after drilling" were within the tolerance range of the corresponding cutting tool. The spread of values in the column "Immediately after drilling" in repeated experiments is due to planned and unplanned replacement of the tools, having various actual sizes of the drill diameter being, however, within the tolerance range.

So, for the equally accurate measurements listed in Table 3, when drilling with diamond tools in the mode characterised by the parameters S_r = 0.005 mm/rev, n = 10.000 rev/min the values of the diameter measurements made in 48 h, mm: 10.072; 10.090; 10.080; 10.071; 10.089; 10.073; 10.081; 10.072; 10.070. The average value was $\overline{x} = 10.077$.

Table 3 Results of error evaluation

Tool usage parameters	Tool	S	$\overline{x}$, мм	x_*, мм	t	$t_n(0, 99)$	Rejection condition
S_m = 50 mm/min n = 10,000 rev/min	Diamond drill	0.008667	10.077	10.090	1.499	3.54	No
	HAM 380 drill	0.0113	10.0355	10.060	2.168	3.54	No
S_m = 75 mm/min n = 15,000 rev/min	Diamond drill	0.0229	10.053	10.02	1.440	3.54	No
	HAM 380 drill	0.015	10.040	10.065	1.666	3.54	No
S_m = 300 mm/min n = 20,000 rev/min	Diamond drill	0.0123	10.051	10.03	1.707	3.54	No
	HAM 380 drill	0.00707	10.023	10.01	1.838	3.54	No

Empirical standard value according to formula (4) was:

$$S = \sqrt{\frac{1}{9-1}\sum_{i=1}^{9}\left(x_i - \overline{10.077}\right)^2}.$$

After substituting the measurement results, we obtained the value:

$$s = \sqrt{\begin{array}{l}\frac{1}{9-1}\left(10.072-\overline{10.077}\right)^2 + \left(10.090-\overline{10.077}\right)^2 + \left(10.080-\overline{10.077}\right)^2 + \\ +\left(10.071-\overline{10.077}\right)^2 + \left(10.089-\overline{10.077}\right)^2 + \left(10.073-\overline{10.077}\right)^2 + \\ +\left(10.081-\overline{10.077}\right)^2 + \left(10.072-\overline{10.077}\right)^2 + \left(10.070-\overline{10.077}\right)^2\big) \\ = 0.008667.\end{array}}$$

For the "upstart" different value 10.090 the ratio (3) is $t = \frac{|10.090-10.077|}{0.008667} = 1.499$.

Using the tables given in Rumshiskiy (1976) for reliability for P = 0.99 and number of experiment n_o = 9, we determined $t_n(P) = 3.54$. Since the obtained ratio t = 1.499 is less than the critical one ($t < t_n(P)$), the value 10.090 should not be excluded at reliability P = 0.99.

Now let us conduct similar evaluation of coarse errors for the remaining modes. For convenience purposes, the calculations were summarised in Table 3.

Thus, all output criteria values in Table 3 at n_o = 9 results for each designated case is less than critical one $t_n(0.99)$= 3.54 at reliability P = 0.99. This is evidences of the absence of grounds for the exclusion of "upstart" different values listed in Table 2.

Based on the results of average values of experimental shrinkage measurement given in Table 2, we have built the bar graphs for diameters for each material grade (see Figs. 9, 10 and 11).

The largest amount of shrinkage was recorded in carbon fibre Porcher. Also smaller shrinkage was recorded in samples of carbon fibre KMU-4E. The most stable was fibreglass VPS-33 – where the shrinkage was hardly recorder. The values of the actual shrinkage values over time (after 48 h) were 0.02-0.03 mm, and the measurement error was 0.004 mm, which allows to deem the measurement results as accurate. Obviously, the carbon fibre, especially the brand Porcher has the properties elastic rheonomic recovery.

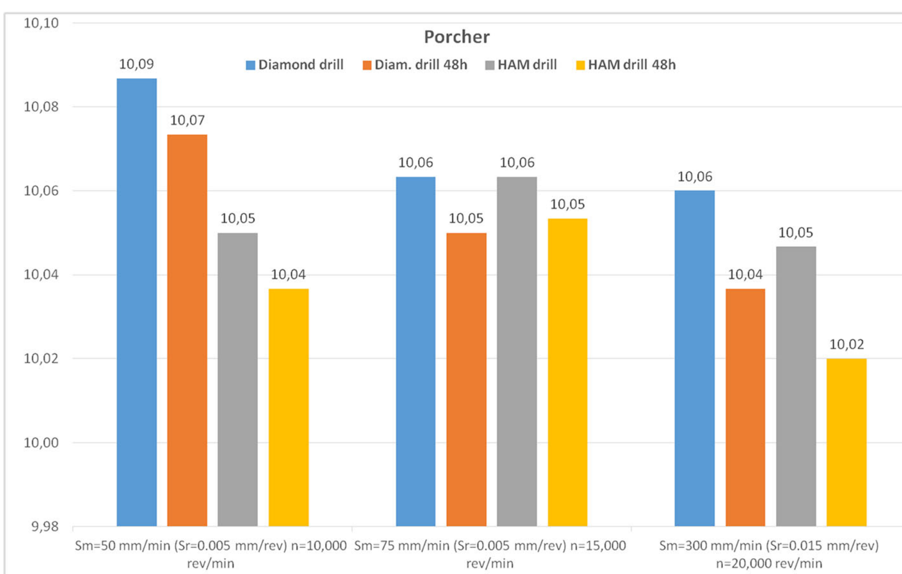

Fig. 9 Dependence of hole diameter immediately after drilling (blue and grey bars) and in 48 h after drilling (orange and yellow bars) with the use of diamond drill and HAM carbide drill for Porcher material under different machining modes

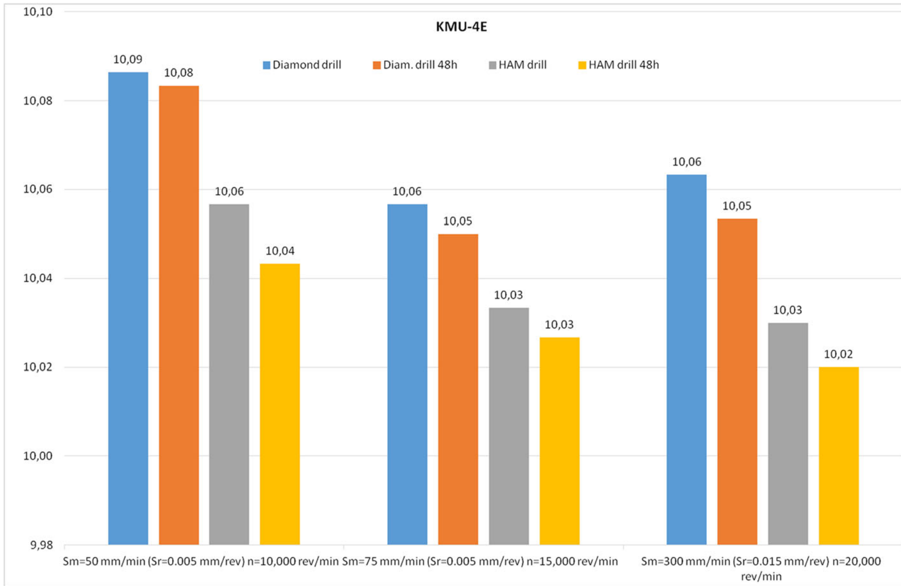

Fig. 10 Dependence of hole diameter immediately after drilling (blue and grey bars) and in 48 h after drilling (orange and yellow bars) with the use of diamond drill and HAM carbide drill for KMU-4E material under different machining modes

It has been observed that the shrinkage parameters are also affected by the processing mode. The assumed causes of the processing mode parameters influence consist of two hypotheses: the first of which is due to the rate, and the second – due to the force factors.

The effect exerted by the processing rate may be explained as follows. When drilling polymer composite materials, elastic deformations do not localize in a narrow cutting zone but spread to the material around the drilled hole. Around the holes on the entire length of the cutting section of the tool, i.e. the entire height of the work piece, elastic compressive stresses emerge. After passing of the cutting section of the tool through the work piece, the forces causing these stresses release, and the material elastically deforms in the opposite direction by reducing the diameter of the drilled hole. The higher the cutting speed is, the more the holes will

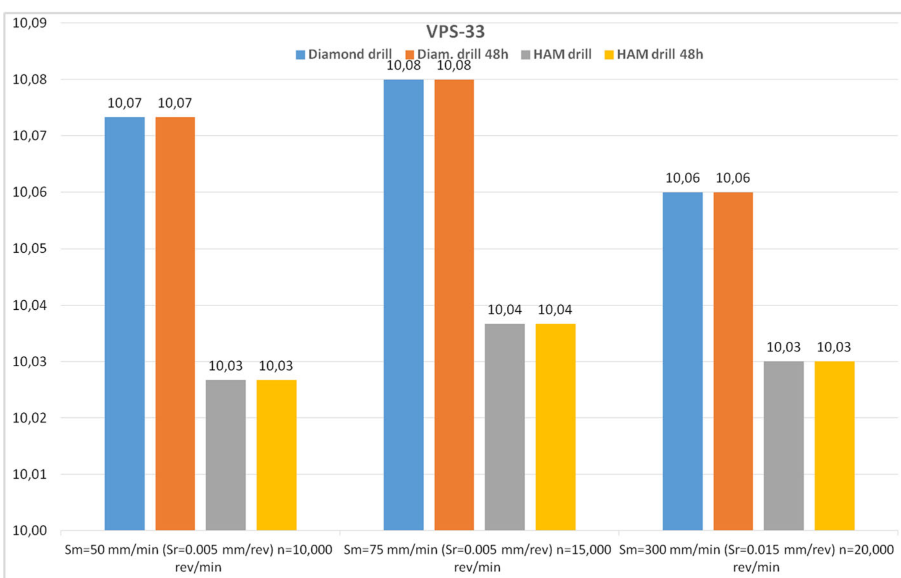

Fig. 11 Dependence of hole diameter immediately after drilling (blue and grey bars) and in 48 h after drilling (orange and yellow bars) with the use of diamond drill and HAM carbide drill for VPS-33 material under different machining modes

shrink. And vice versa, the lower the cutting speed is, the more time the cutting tool is in contact with the inner surface of the hole and, therefore, the smaller is the shrinkage. That is, if the polymer composite material "gets used", the shrinkage does not occur, if the material lacks time to "get used" to the tool, the shrinkage emerges.

The second hypothesis may also be suggested stating the influence of processing mode parameters on shrinkage. Elastic rheonomic aftereffect of the material and reduction of the diameter of holes depends on the forces acting during cutting. The greater the forces acting during drilling are, the higher elastic deformation after removal of stresses and reaction forces they cause as the Ostrosablin (1984) and, therefore, the larger the shrinkage is and the smaller the hole diameter after processing becomes. That is, the effect of the 'shape memory' of the hole will be observed after temporary application of force and temperature fields, and the larger they are, the bigger the shrinkage of the hole is.

The final answer can be received with a mathematical simulation of the drilling the polymer composite materials using engineering analysis packages (LS-DYNA, ABAQUS, DEFORM, etc.).

Conclusions

Experimental research to determine shrinkage of the holes after drilling samples made of polymer composite materials with the subsequent control using optical measuring system ATOS III Triple Scan XL was conducted. Such experimental data are necessary in order to predict formation of actual diameters of holes; shrinkage values are useful for technologists and designers of machine-building enterprises.

The experiments utilised different types of cutting tools for drilling holes with a diameter of 10 mm (tolerance D10), Parameters of sample processing modes of polymer composite materials of different brands varied.

It was determined experimentally that the grade of the processed polymer composite material has the largest influence upon holes shrinkage. The amount of shrinkage is also affected by the combination of machining mode parameters. The influence of the cutting tool type is of insignificant effects upon shrinkage.

Abbreviations

PCB: Printed circuit board; rev/min: Revolutions per minute; rpm: Revolutions per minute; STL: Stereolithography file format

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Authors' contributions

Authors have made substantial contributions to the concept, design, acquisition of data, and analysis and interpretation thereof. Authors participated in drafting the article and its further critical revising for important intellectual content. All authors have read and approved the final manuscript.

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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