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V. Kolesnyk, J. Zajac, S. Radchenko, M. Adamian

THE EFFECT OF CUTTING TEMPERATURE ON HOLE QUALITY WHEN DRILLING CFRP/METAL STACK

The carbon fiber reinforced plastic (CFRP) are widely used in stacks with metals. That allows obtaining components with high strength and reduces weight. Holes' drilling is a basic operation of CFRP/metal and metal /CFRP stacks machining. The most common problems of CFRP/metal stacks drilling are CFRP delamination, fiber pull – out, thermal degradation and low quality of hole surface. In this study the effect of cutting temperature on the hole quality was provided. It was experimentally established that drilling of CFRP/metal stack was accompanied with a significant change of cutting temperature in the cutting zone during the transition of drill from CFRP to metal plate.

Key words: drilling, hole surface integrity, accuracy, CFRP/metal stack, drill wear, cutting temperature.

Introduction. In the last two decades composites materials have taken leading positions and exclude traditional construction materials in the aircraft building and power engineering. CFRP could be shaped in a complex form so the necessity in milling and turning operations significantly reduce. However, there is a need for assembling CFRP parts with metal one. In such a way the most widespread machining processes are: drilling, reaming, countersinking. Machining of CFRP parts, is associated with considerable difficulties due to multi component structure of these materials [1]. There are substantial problems with the quality and accuracy of the machined surface. It is well known fact that the quality of machined holes in CFRP determines the life cycle of the joints in CFRP/metal stacks [2].

State of the art. According to a study W. Xin, Y.K Parick, S. Caleb et al. (2014) researches used CFRP (7.54mm) / Ti (6.73mm) stacks. Researches studied influence of cutting conditions operation on tool wear during CFRP/Ti alloy drilling. As a tool material was chosen - uncoated WC-9% Co, drill with Ø 9,525 mm, flute length 38,1 mm and double point angle 2φ=135°. Drilling conditions are used throughout the experiment was 6000 rpm, feed rate of 0,0762 mm/rev for CFRP, and 500 rpm, feed rate of 0,0508 mm/rev for titanium alloy respectively. Drill wear was studied on the flank surface near corner and chisel edge. It was found that different cutting conditions for CFRP and titanium alloy provokes less wear of cutting tool. In experiments it was indicated that the tool life attainable in drilling of the CFRP/Ti alloy stack was about three times longer compared to that attainable in drilling of Ti alloy only. Authors concluded that effect of cutting temperature on tool wear mechanism is not yet well studied [3].

A. Poutord, F. Rossi, G. Poulachon, M'Saoubi R (2013) provided research on drilling CFRP (25.5 mm)/ Ti6Al4V (20.7 mm) stack by WC Ø12 mm drill, with flute length 55 mm, double point angle 2φ =140°. When drilling stack the adaptation of cutting conditions V=100 m/min, f=0,05 mm/rev and 10 m/min and 0,2 mm/rev for CFRP and Ti machining respectively was used. Measurement of axial force distribution along primary cutting edge and proved that wear of chisel edge provokes delamination. It can be concluded that the major tool wear comes from the CFRP material. The wear generated by Ti6Al4V is mostly confined to cutting edge chipping on the drill corner [4].

O. Pecat, E. Brinksmeier (2014) provided the research which was focused in study influence of low frequency vibration assisted drilling (LFVAD) to the surface integrity of CFRP (10 mm)/Ti6Al4V (10 mm) compound stacks compared to conventional drilling. Research was implemented using twist drill with Ø4,83 mm, double point angle 2φ=120 °, helix angle 30°. When drilling cutting speed and feed was 15 m/min 0.075 mm/ rev respectively. LFVAD method was realized with amplitude 0,115 mm and frequency 1,5 oscillations/rev. It was concluded that thermo mechanical damages of the CFRP layer and high cutting temperatures in titanium are mainly caused by insufficient extraction of metallic Ti-chips which are reaming at the newly generated bore surface. The exit burr height in Ti6Al4V is significantly decreasing due to lower process temperatures in LFVAD [5].

Crisan L.A., Pop G.M. conducted a research on machining CFRP with WC drill bit, double point angle 2φ=118° and 155° and found that the drill bit geometry influence on cutting temperature when machining CFRP. When machining with drill that has 2φ=118° the temperatures registered with the IR camera were higher than 145°C, at the same time when machining with drill 2φ=155° registered temperatures didn't overcome 85°C. It was found that surface roughness parameter Ra decreases with the increase of the spindle speed when processing with drill bit 2φ=118°.The surface roughness parameter Ra increases, up to 18µm, with the increase of the feed, when processing with tool 2φ=118°[6].

Despite of many studies reported on the drilling CFRP/metal stacks the fundamental understanding of cutting temperature in drilling stacks and the relationship with hole accuracy and quality is not known. There are some research which was targeted to uncover influence of cutting temperature on the hole quality when drilling CFRP but study on measuring cutting temperature during machining CFRP/metal stack has not yet done.

The purpose of current paper is to explore the influence of cutting temperature on quality of hole and surface integrity when drilling CFRP/steel stacks with carbide drill.

Problem statement. Current study is targeted to explore the change of cutting temperature in the process of CFRP/metal stack drilling in conditions of different wear rate of the drills and their influence on the holes' quality. It is well known fact that CFRP have high heat capacity and low thermal conductivity [7]. That circumstance creates favourable conditions for thermal integrity of machined surface and descries its quality. Other limitation factor is feed rate. So far that cutting parameter contributes much in formation of delamination of CFRP. That specific damage of CFRP layers reduce bearing capacity of bolted joist [2].

Nowadays researches and manufactures have already worked out guidancens for machining CFRP with cutting conditions: cutting speed rate 15 - 180 m/min and feed rate 0,02-0,15 mm/rev [3, 4, 5]. With it recommended cutting conditions for metallic materials vary for cutting speed rate 9 - 80 m/min with feed rate 0,02-0,2 mm/rev [3, 4, 5]. Such a big variety of cutting conditions for drilling CFRP/metal stack could involve rapid tool wear, low quality of the hole, low productivity. Rapid tool wear of carbide drills during machining of CFRP/metal stacks can be involved by high temperature in the cutting zone. That can lead to thermal degradation of epoxy matrix, reduce hole integrity and degrade quality and accuracy of the hole. Because of it in the current research it is proposed to investigate influence of cutting temperature when drilling CFRP/metal stack with constant cutting conditions on quality and accuracy of the hole.

Experimental setup. Workpiece materials which were used for experimental study was CFRP/metal stack. The metallic plate used in the experiment was steel 1.0114 (EN 10025-2) with a thickness of 5 mm and a hardness of 140HB, tensile strength - 400 MPa, density - 7.83 g/cm^3 provided from supplier. The CFRP plate was manufactured via hand layer technique of unidirectional carbon followed by vacuum forming at 35° C for 5 hours. Vacuum bag was manufactured by Airtech application such as Securlon L-500Y, AT 199 and Ultraweave 1332. Vacuum pump provided the pressure in 0,26 .10^{-3} Pa. Epoxy resin Lorit 285 mixed with the hardener in the ratio 5:2 was used as a matrix for carbon fiber. The mass content of carbon fiber was about 60% for the total mass of the plate. The CFRP plate had a thickness of 5 mm with an average ply thickness of 0.15mm. The average diameter of the carbon fiber was 10 μm.

Uncoated drill made of WC-9% was used in this research. The drill had macro drill geometry with the outside diameter being 10 mm and the flute length being 47 mm. The shank diameter and overall length were 10 mm and 89 mm, respectively. The drills had the standard configuration with two flutes with the helix angle of 25° and a right hand spiral and cut. The drills had the double point angle of 135° with cut chisel edge 0,5 mm thickness. For measuring cutting temperature when drilling CFRP/metal stack on the flank surface of the drill there was embedded K-type (chromel - alumel) thermocouple (Fig.1).

Drilling experiments were carried out on 16Б16Т1 CNC lathe machine (Fig. 2) (Sumy, Ukraine). CFRP (5 mm)/ steel (5 mm) CFRP layer was laid on the top of the steel one.

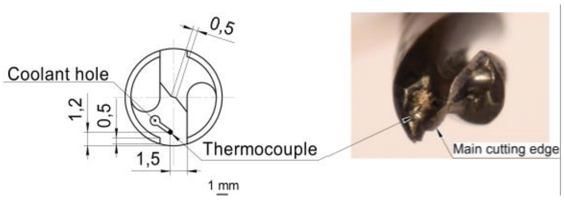

Fig. 1 – Schematic of thermocouple embedment

The chosen stack sequence of top CFRP and bottom metal is the most common material sequence for stack materials in aircraft and automobile industry. The experiment set-up (Fig. 1) consists of workpeice which was fixed in the chunk. Thermocouple which was embedded in the carbide drill was connected to temperature transducer and analog – digital converter ADC (LTR11). The measuring range of thermocouple is 0 – 1000°C measurement error to temperature transducer is 2% of the measured value. Drill was fixed in the grinned plate and clamped in dynamometer (УДМ 100) which was used for measuring axial force. Dynamometer has measurement range up to 1000 N. It was followed by signal amplifiers and the ADC (LTR212). Frequency of decartelization of measured values was 150Hz. All measuring systems were connected to personal computer.

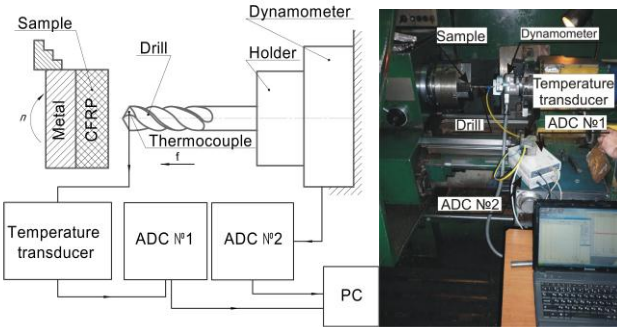

Fig. 2 – Drilling experimental set up at CNC Lathe machine 16Б16Т1

Drilling condition throughout the experiment was 37 m/min cutting speed and 0,02 mm/rev feed.

In the framework of this research several measurement techniques were used. Measurement of drill flank wear was implemented on optical microscope МБС-9 (Fig. 3).

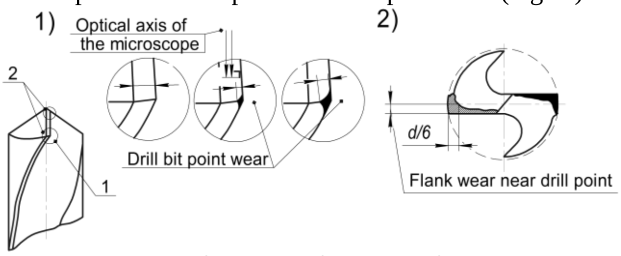

Fig.3 – Schematic of measuring flank wear of the drill on instrumental microscope

As a criterions for quality rating in CFRP plate was delamination factor (Equ.1), thermal degradation and fiber pull out absence which was measured on optical microscope KAPA 9000 with accuracy to 1 μm**,** surface roughness (Ra)-MitutoyoSurftest SJ 400 (Presov, Slovakia). In steel layer a criterions for quality are surface roughness and holes' accuracy. Accuracy of holes in both plates was measured with CNC coordinate measuring machine Thome Precision accurate within 2 μm.(Presov, Slovakia) (Fig. 4).

$$F_d = \frac{D_{max}}{D} \quad (1)$$

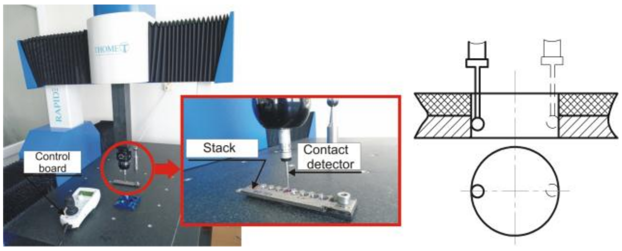

Fig. 4 – Schematic of measuring hole accuracy

Experimental results. During the experiment 49 holes were manufactured in CFRP/ steel stack, and eight check points of axial force and cutting temperature were determined (Fig.5, Fig. 6). It was found that drilling for stack can be characterized by six steps in dependence chisel edge position in the stack.

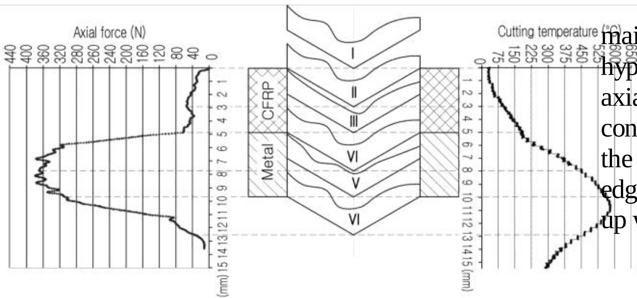

Fig. 5 – Axial force and cutting temperature during the 17th hole machining with WC drill bit (V= 37 m/min, f=0,02 mm/rev)

It was established that tool wear influence cutting temperature and axial force. Comparison of experimental results of drilling holes 17 and 37 uncover cutting temperature trend to grow in the transition layer as well as in each stack material. Thus cutting temperature increased by 10 % in CFRP and 27% in the metal. However, the axial force increased by 43 % during drilling CFRP and 5% in the metal. Mechanical properties of CFRP are characterized by high plasticity and low hardness. This, along with low temperature degradation of CFRP and closeness of the cutting zone creates favorable conditions for setting CFRP particles on the rake surface of the drill and the build-up formation during drilling. In certain conditions, it can limit heat transfer in the tool. As build-up increase the heat flow in the tool is weakening, which is accompanied by a decrease of cutting temperature. After built-up separation the obstacle for heat flow disappear, that contributes to heat dissipation in the tool (Fig. 6), and leads to cycle changes of cutting temperature.

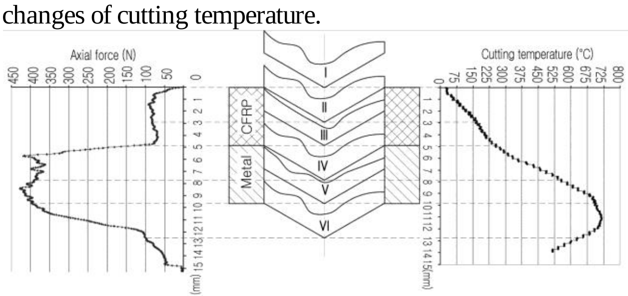

Fig. 6 – Axial force and cutting temperature during the 37th hole machining with WC drill bit (V= 37 m/min, f=0,02 mm/rev)

Progress of flank wear was accompanied with raise of axial force when drilling CFRP and reduction during steel plate drilling (Fig. 7). That is owing to higher sensibility of CFRP to chisel edge wear in comparison with steel.

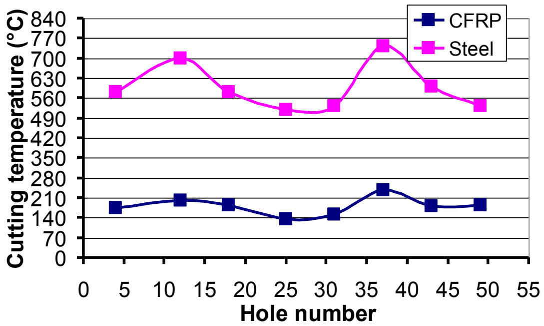

Fig. 7 – Cutting temperature vs number of holes drilled in CFRP/ steel stack

However, some axial force variation is effected by main cutting edge build-up. This effect is consistent with the hypothesis of build-up influence on the cutting edge and axial forces growth. Built-up increase rake angle that change conditions of chip formation in the cutting zone. Therefore, the stagnant zone, which was formed around the cutting edge, accompanied axial force reduction. The CFRP build-up was removed by hard steel chip from the rake surface.

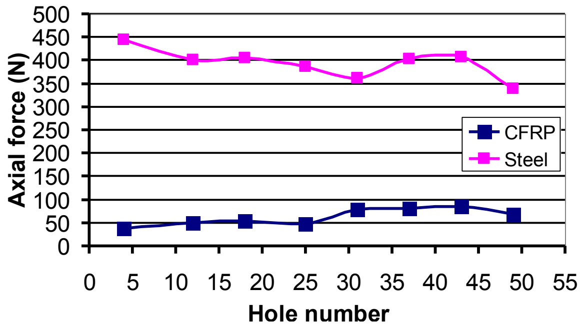

Fig. 8 – Axial force change during CFRP/steel stack drilling

Hole accuracy is much effected by cutting temperature and axial force. Built –up formation creates unfavorable conditions for chip formation and heat transfer. In such circumstances the hole accuracy decrease in CFRP part faster then in metallic one (Fig.9). Rapid reduction of hole accuracy is connected with drill bit point wear and it effects more in CFRP than in steel because fiber are cracked but not cut. It is one more reason to observe uncut fibers in CFRP (Fig. 12)

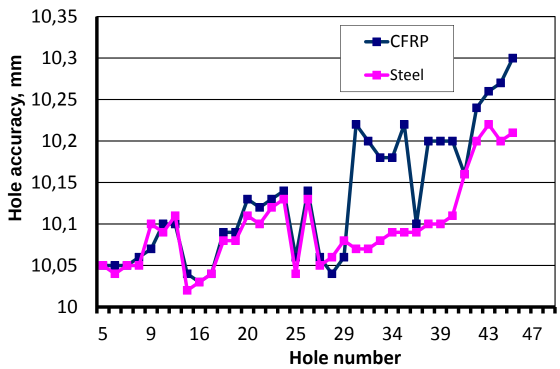

Fig 9 – Hole accuracy of CFRP/Steel per layer

Surface roughness increase due to growth number of uncut fiber (Fig.10). It can be concluded that CFRP are more sensible to drill wear than metallic materials.

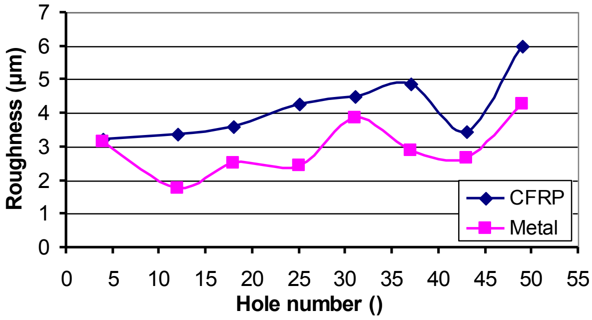

Fig. 10 - Hole roughness in CFRP and Steel part

Rapid increase of delaminated is closely connected with intensive chipping of cutting edge and point rounding.(Fig. 11).

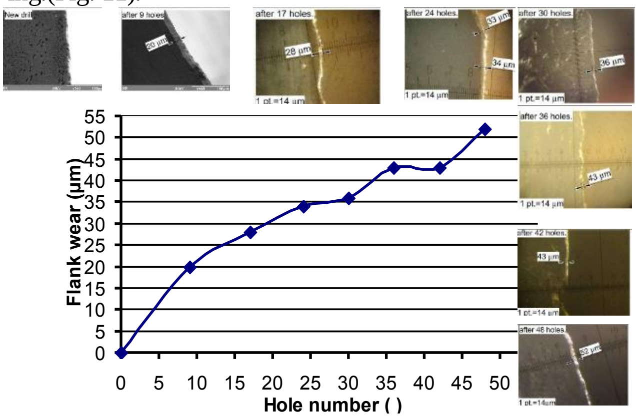

Fig. 11 – Progress of flank wear during CFRP/steel stack machining

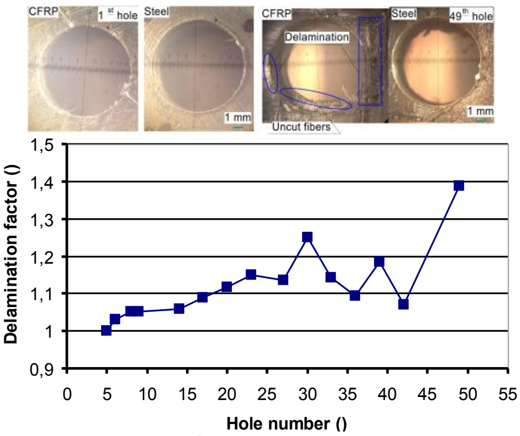

Fig. 12 – Progress of delamination when drilling stack

Conclusions. Drill bit motion in CFRP/Steel stack was characterized by six steps according to it position in hole during machining. The lowest values of cutting temperature as well as axial forces during machining CFRP with new drill was 174° C and 40 N respectively. At the same time during drilling metal axial force was 430 N and the temperature of 580 °C. Chisel edge contact with metal layer provoke rapid growth of axial force to it maximum, while cutting temperature increased as far as main cutting edged entered in material.

Simultaneous machining of CFRP and Steel provokes a rapid rise of cutting temperature in the cutting zone in comparison with the drilling CFRP only. Thus, during CFRP drilling cutting temperature rise at 8,9°C/s, while during simultaneous CFRP/ Steel cutting - 31,7°C/s.

When drilling CFRP/ Steel stack the hole accuracy reduce to 250 µm while in steel only on 150 µm due to abrasive bulk effects of rough metallic chip.

Surface roughness in CFRP changed from 3 to 6 µm, and in steel from 3 to 4.2 µm. It proves that CFRP is more sensible to drill bit point wear.

Delamination of upper layers of 49th hole growth at 30% in cooperation to 1st one.

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Колесник Виталий Александрович – м.н.с. кафедры технологии машиностроения, станков и инструментов Сумский государственный университет, тел. (050) 40-64-232, e-mail: kol-vitaliy@ ukr.net.
Заец Йозеф – канд. техн. наук, декан Факультета производственных технологий, Кошецкий технический университет, Прешов, Словакия
Радченко Светлана - аспирант кафедры производственных технологий, Кошецкий технический университет, Прешов, Словакия
Адамян Марина Артуровна – магистрант, Сумский государственный университет