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THE EFFECT OF TOOL WEAR ON CUTTING TEMPERATURE WHEN DRILLING CFRP/STEEL STACKS

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О ВЛИЯНИИ ИЗНОСА ИНСТРУМЕНТА НА ТЕМПЕРАТУРЫ РЕЗАНИЯ ПРИ СВЕРЛЕНИИ ПАКЕТА УГЛЕПЛАСТИК/СТАЛЬ

This paper presents tool wear study based on the drilling experiment of CFRP/ steel stack. The most common problems of CFRP/metal stacks machining are CFRP delamination, fiber pull – out, thermal degradation and intensive tool wear. Last decade such parameters of CFRP/metal stacks drilling as axial force and torque are in the focus of researches. However, the cutting temperature in the drilling process of CFRP/metal stack and its influence on drill bit wear is still not fully gained at the present time. The purpose of current study is to investigate the effect of cutting temperature on the tool life of carbide drill. The temperature was measured with K type thermocouple which was embedded on the flank surface of the drill. Axial force was measured with dynamometer. Data of cutting temperature and axial force was digitalized with analog – digital converter (ACD) and visualized on personal computer (PC). The dominating tool wear mode when drilling CFRP/steel - was flank wear which was measured with optical microscope. The experimental study of cutting temperature effect on the tool wear of carbide drill was established. It was found that the most unfavorable combination of stack materials in the conditions of drill wear is CFRP/metal.
Keywords: composite, tool geometry, force, carbide tool, temperature measurement

Introduction

Recently 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 thus the necessity in milling and turning operations is significantly reduced. However, there is a need for assembling CFRP parts with metallic one. In such a way the most widespread machining processes are: drilling, reaming and 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 [2].

The usage of single drill for machining CFRP and titanium alloy layers leads to trade-off in cutting conditions and cutting tool geometry which often leads to increasing of cutting force and decrease the quality of the holes [3].

Parameters which characterized tool wear in the process of CFRP/ titanium alloy stack are flank and cutting edge rounding wear [4, 5, 6]. W. Reimann investigated the effect of different values of edge rounding wear on the chip formation and surface quality during high-speed milling of CFRP and had determined that the cutting tool with corner radius 50 μm leads to a very poor quality of the machined surface. However corner radius 60 μm did not effect the cutting force value [7]. A. Fazar occured by observed similar effect on the torque during process of CFRP drilling [5]. However, the magnitude of axial force in their experiments was not constant due to the increased friction between the tool and the machined lateral of the hole. Numbers of holes are used as a criterion of tool life evaluation in practice. R. Zitoune concluded that the wear mechanism of the carbide in the process of CFRP/ titanium alloy drilling was studied insufficiently [8, 9].

The purpose of present study is to explore the change of cutting temperature in the process of CFRP/steel stack drilling in conditions of various wear volume of the drill.

Research methodology

Full-scale experiment of CFRP/steel and steel/CFRP stacks drilling was carried out in that study. The study was implemented in two steps: case study which was aimed to define influence of stack material combination on the cutting temperature and basic study to explore effect of cutting temperature on carbide tool wear. Samples had predetermined shape and properties. They were manufactured with hand layer technique of unidirectional carbon fiber on steel 1.0114 (EN 10025-2) plate, 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. CFRP plate has

0/90°fiber orientation scheme. Stack consists of 5 mm CFRP and 5 mm steel 1.0114 plates. Steel 1.0114 has following properties: hardness – 140HB, tensile strength - 400 MPa, density - 7.83 g/cm^3 . Stack machining was provided with ø 10 mm HSS and WC twist drills. HSS drill that was used in case study had double point angle 2φ = 118°. The chisel edge thickness was 0,8 mm, length of the main cutting edge – 5,83 mm, tool point - 3 mm. K Type thermocouple was placed in 1,5 mm away from main cutting edge and 1,2 mm beyond the drill point. Carbide drill geometry was characterized by double point angle 2φ = 135 °, with the 0,5 mm chisel edge thickness. The thermocouple was embedded at the distance of 1.5 mm from the main cutting edge and 2 mm away from drill corner on the flank surface (Fig. 1).

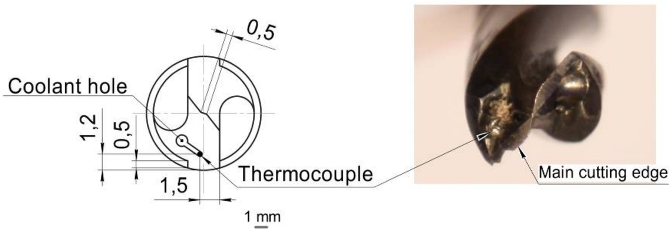


Fig. 1. The scheme of thermocouple embedment

Cutting conditions throughout the case study for HSS drill was 560 rpm and feed volume 0,01 mm/rev. Drilling with WC was carried out at 800 rpm and 0,02 mm/rev respectively. Experimental studies were implemented in 16Б16Т1 CNC lathe machine (Fig. 2) and FADAL 2216 - FX milling machine (Fig. 3). 16Б16Т1 CNC lathe machine was used in case study the purpose of which was to determine the influence of combination of stack materials (CFRP/ steel, steel/ CFRP) on cutting temperature. During basic experiment 16Б16Т1 CNC lathe machine (Fig. 2) was equipped with dynamometer for measuring axial force.

Drill was motionless makes possible to measure the axial force and temperature, but only one hole in the workpiece could be provided. During machining on the 2216 -FX FADAL workpiece was fixed, and the drill was rotating. On this set up, only the axial force was measured, but the large amounts of holes were produced. Axial force was measured with dynamometer with measuring range from 0 to 1000 N and accuracy to 1%. Dynamometer was followed by analog - digital converter (ADC) for digitizing data and transfers it to a PC. The temperature was measured with measuring system, which consists of K type thermocouple, temperature transducer and ADC (Figure 2). This system allows measuring the temperature in the range of 0° - 1000 °C, with an accuracy of 2 %.

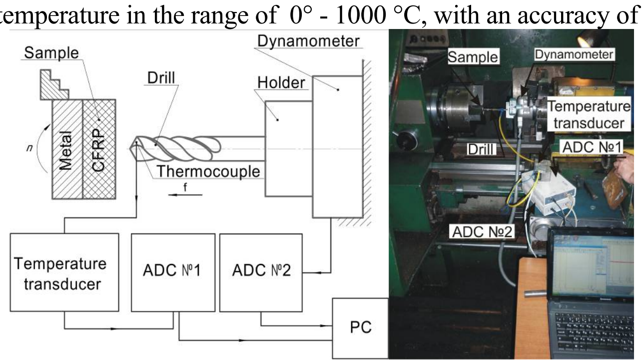


Fig. 2. Drilling experimental set up at CNC Lathe machine 16Б16Т1

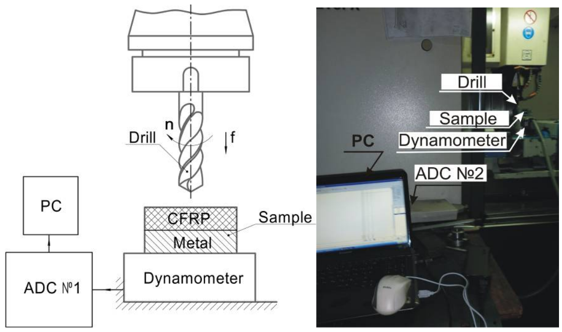


Fig. 3. Drilling experimental set up at 2216 - FX FADAL

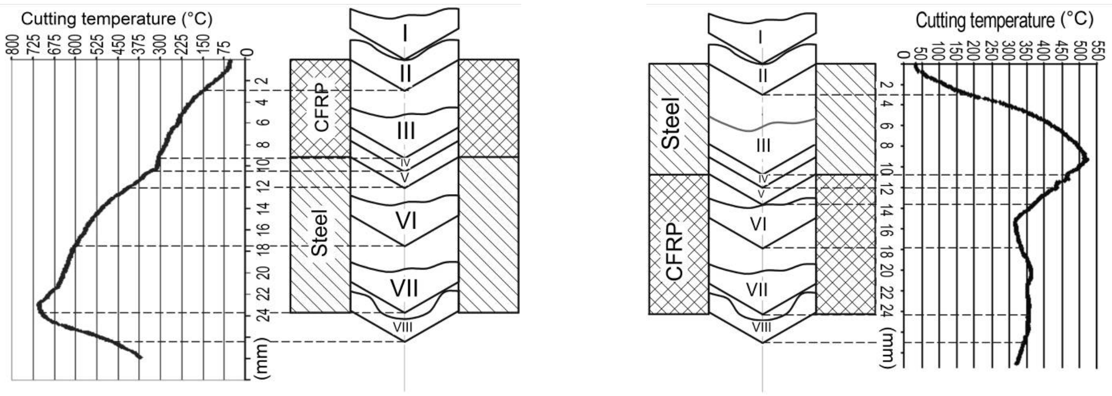
Basic maintenance and results of research

During case study the effect of stack material combination was studied. Experiment was implemented for CFRP/ steel and steel/ CFRP stack combination. When drilling stacks the HSS drill was motionless. Drilling of stacks can be described in eight steps. The first step was entry of chisel edge. On the second step entry of tool point was characterized with rising of cutting temperature from 40°C to 157°C, volume of heat flow was 1312 V/m^2. On the third step the steady-flow process of CFRP cutting which last till chisel edge touched steel plate, volume of heat flow was 5187 V/m^2 and cutting temperature increase from 157°C to 309°C. Source of heat generation on that step was transformation of frictional energy of CFRP and carbide. On the fourth step cutting temperature raised to 340°C. Machining of steel plate was divided into 4 steps (V-VIII). The process was accompanied with cutting temperature growth up to 730°C, and heat flow in tool reached 10956 V/m^2 just before exiting the drill out of the stack. The highest cutting temperature in CFRP was 313°C.

When drilling holes in steel/CFRP stack the highest cutting temperature in steel was 521° C and 363°C in CFRP (Fig. 4). The area of simultaneous machining steel and CFRP was of particular interest. Preliminary heating of the drill during machining of steel plate caused decrease of cutting temperature at 4 °C/s. That had reduced the mechanical work for break up of adhesive connections between matrix and carbon fiber, and consequently reviled in cutting temperature reduction.

However, that effect had limitation and after temperature reached minimum of 318 °C on that step, the cutting temperature rose up to 355°C. Cutting temperature growth is connected with adaptation of the drill to new cutting conditions in CFRP and less transition of heat in CFRP chip.

Thus, during drilling stack from CFRP side (Fig. 4 (a)), the maximum cutting temperature was nearly 200°C more than during drilling from steel side (Fig. 4 (b)).



a *b*

Fig. 4. Cutting temperature volume during HSS drill machining CFRP/Steel and Steel/CFRP stacks (V=17 m/min, f=0,01 mm/rev)

This is because of more complicated conditions of chip transfer from the cutting zone, CFRP chip packaging, and its low thermal conductivity. On the other hand, the maximum cutting temperature of CFRP during CFRP/steel machining was 35-44°C less then during steel/CFRP stack drilling. The reason of it is better heat dissipation into the tool. The cutting temperature volume in the first case is less then in the second one (18.8°C/mm vs. 36 °C/mm), but it should be specified that 18.8°C/mm was temperature of heating, while 36°C/mm –cooling one. Based on the above it can be stated, that CFRP/steel stack drilling is less emphasize stack material combination in terms of cutting temperature and its influence on CFRP matrix degradation. On this basis the CFRP/steel stack was used for further research of cutting temperature effect on carbide drill life.

Before conducting experiment the main cutting edge was observed in scanning electronic microscope РЭМ 100У cutting edge radius 7 μm was measured. During the experiment 49 holes were machined in CFRP/steel stack, and 8 of them were drilled in circular samples as axial force and cutting temperature and axial force were measured. Other holes were drilled in CFRP/steel plate on 2216 -FX FADAL. Comparison of cutting temperature and axial force during basic research is provided on Fig. 5, Fig. 6.

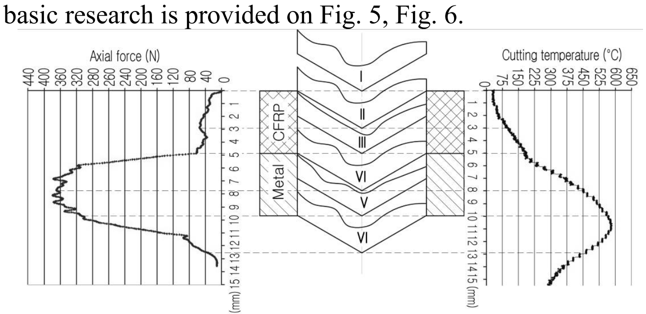


Fig. 5. Axial force and cutting temperature during the 17th hole machining with WC drill bit (V= 37 m/min, f=0,02 mm/rev)

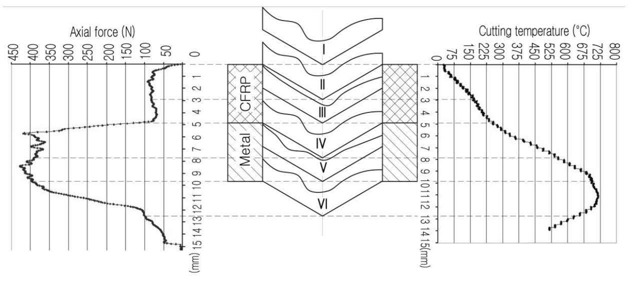


Fig. 6. Axial force and cutting temperature during the 37th hole machining with WC drill bit (V= 37 m/min, f=0,02 mm/rev)

The cutting temperature and axial force was compared while drilling the 17th hole and the 37en holes. Cutting temperature increased on 10 % in CFRP and 27% in the steel and axial force increased on 43 % in CFRP and 5% in steel plate respectively. Mechanical properties of CFRP are characterized by high plasticity and low hardness. Combination of low temperature of epoxy resin degradation and high temperature in the cutting zone created favorable conditions for setting CFRP particles on the rake surface of the drill and formation of build-up. In certain conditions, built-up can limit heat transfer in the tool. With build-up growth the heat flow in the tool become inefficient. This process is accompanied by a decrease of cutting temperature. After built-up separation the obstacle for heat flow disappears, which brings to heat dissipation in the tool (Fig. 6), and leads to cycle changes of cutting temperature.

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. 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 (Fig. 7). 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.

The build-up did not affect the process of flank wear. Flank wear was formed by abrasive action of carbon fiber on the cutting edge. Progress of flank wear provokes reduction of main cutting edge strength which leads to chipping. In the considered conditions, the average wear volume was about 1,08 μm/hole. The average wear volume decreases with increasing number of holes: 2 μm/hole during drilling holes № 1-5 – 0,7 μm/ hole – drilling holes № 7-17 and holes

№18-24. Wear volume of main cutting edge when drilling holes №25-30 changed 0,4 µm/ hole. So it can be concluded that during drilling holes №1-24 the early failure period of drill bit was observed. After drilling holes № 31-36 the wear volume was 1,17 µm/ hole though machining holes №37 - 42 the flank wear did not change, thus it was the period of steady wear. On the last series the wear volume was 1.5 µm/ hole (Fig. 8). Up to the 17th hole chipping was not observed. Changing of cutting edge shape occurred uniformly by continuous abrasion on the flank surface. Chipping of main cutting edge was observed after 17th hole (Fig. 9). Chipping of the main cutting edge № 1 was 0,255 x1,05 mm, flank wear was 42 µm, flank wear on main cutting edge № 2 was 73 µm.

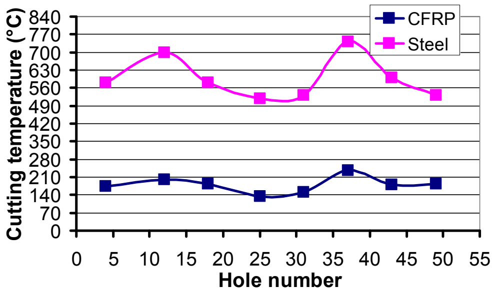


Fig. 7. Cutting temperature vs number of holes drilled in CFRP/ steel stack

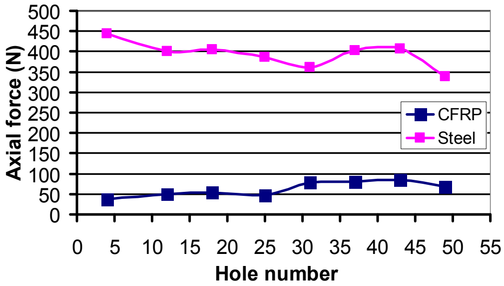


Fig. 8. Axial force change during CFRP/steel stack drilling

Moreover the geometry of carbide drill outer corner on the main cutting edge № 1 changed with a radius of 4.34 mm. Thus, despite the fact that the drill bit did not loss it availability and flank wear was 0,05 mm. It is not longer possible to use it further for machining holes with proper quality. Therefore, the criterion for work capacity of a drill when machining CFRP (0°/90°) /steel stacks should be flank wear 0,03 mm, as the proper quality of CFRP surface without delamination and fiber pull out could be provided.

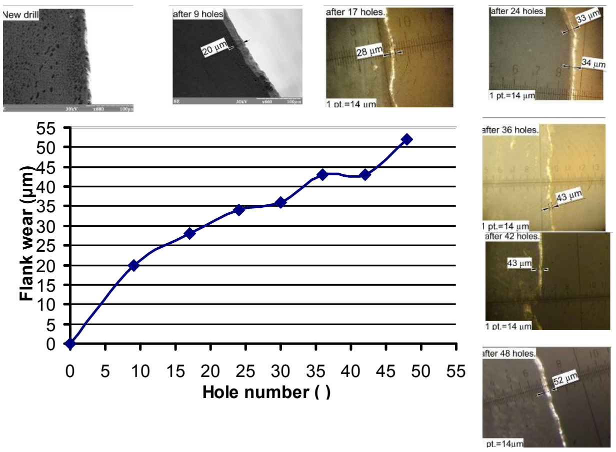


Fig. 9. Progress of flank wear during CFRP/steel stack machining

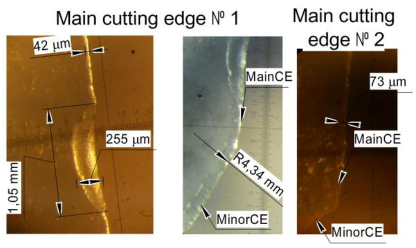


Fig. 10. Cutting edge chipping and outer corner rounding

Conclusions

Carbide 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 steel axial force was 430 N and the temperature of 580 °C. Chisel edge contact with steel layer provoke rapid growth of axial force to it maximum, while cutting temperature increased as far as main cutting edged entered in material.

The most unfavorable combination of stack materials package, in terms of the effect of cutting temperature on tool life and machined material was combination CFRP/steel. 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.

The average wear in the considered cutting conditions was about 1,08 µm/ hole , decreasing with increasing number of holes from 2 µm/ hole when drilling holes № 1-5 to №25-30 changed 0,4 µm/ hole. The total flank wear was 52µm after drilling 49 holes. Cyclic ups and down of cutting temperature as well as axial force set conditions for built-up formation and removal.

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Анотація. *У статті представлені дослідження зносу інструменту, в процесі свердління пакетів вуглепластик / сталь. Найбільш поширені проблеми механічної обробки пакетів вуглепластик / метал є розшаровування, витягування волокно, термічної деструкції та інтенсивного зношування інструменту. В останнє десятиліття у фокусі досліджень при свердлінні пакетів перебували такі параметри процесу різання як осьова сила і крутний момент. Разом з тим, температура різання в процесі свердління пакетів та її вплив на зношування свердла досліджені в недостатній мірі. Метою даного дослідження було вивчення впливу температури різання на стійкість твердосплавного інструменту. Температура вимірювалася методом штучної термопари К типу, яка розміщувалася по задній поверхні свердла. У ході експерименту осьова сила вимірювалася за допомогою динамометра. Дані про температури різання і осьової силі була оцифровані аналого - цифровим перетворювачем (АЦП) LTR212, LTR 11 і візуалізували на персональному комп'ютері (ПК). Зношування інструменту оцінювався за критерієм фаски зносу по задній поверхні на оптичному мікроскопі МБС-9. Було встановлено вплив температури різання на зношування твердосплавного свердла при свердлінні пакету вуглепластик / сталь. Найбільш несприятливою комбінацією матеріалів пакета є поєднання вуглепластик / сталь.*
Ключові слова: *композит, геометрія інструменту, сила, твердосплавний інструмент, вимірювання температури*

Аннотация. *В статье представлены исследования износа инструмента, в процессе сверления пакетов углепластик / сталь. Наиболее распространенные проблемы механической обработки пакетов углепластик/металл является расслаивания, вытягивание волокно, термической деструкции и интенсивного износа инструмента. В последнее десятилетие в фокусе исследований при сверлении пакетов находились такие параметры процесса резания как осевая сила и крутящий момент. Вместе с тем, температура резания в процессе сверления пакетов и ее влияние на износ сверла исследованы в недостаточной степени. Целью данного исследования было изучение влияния температуры резания на стойкость твердосплавного инструмента. Температура измерялась методом искусственной термопары К типа, которая размещалась по задней поверхности сверла. В ходе эксперимента осевая сила измерялась при помощи динамометра. Данные о температуры резания и осевой силе была оцифрованы аналого - цифровым преобразователем (АЦП) LTR212,LTR 11 и визуализировали на персональном компьютере (ПК). Износ инструмента оценивался по критерию фаски износа по задней поверхности на оптическом микроскопе МБС-9. Было установлено влияние температуры резания на износ твердосплавного сверла при сверлении пакета углепластик/сталь. Наиболее неблагоприятной комбинацией материалов пакета является сочетание углепластик/сталь.*
Ключевые слова: *композит, геометрия инструмента, сила, твердосплавный инструмент, измерение температуры*

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