Microstructure, microhardness and general characterisation of sintered tools using for flanging of hole edge by Flowdrill technology

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Abstract. This paper presents the study results focused on selected properties of sintered materials used for produce the tool for thermal drilling process (Flowdrill). The studies were carried out on a several series of commercial tools of Flat type from dimension 4.5 to 7.3 mm. Microstructure, microhardness, chemical composition as well as surface roughness parameters were investigated. These studies was carried out both before and after drilling processes. On the base of microstructure and chemical composition study, the content of carbides phases and content of porosity in material were determined. Additionally, in the case of tools which have been damaged during the process, the type of fracture was determined. On the fracture surfaces the beach marks were observed, thus confirming that it was fatigue crack. The possibility of applying the Flowdrill technology in industry were also described in this paper.

1. Introduction

Hole flanging is a process often used in industry and often described in the literature. The authors present both traditional winding methods [1-3] as well as other solutions, eg. by means of one-point incremental forming of both metals and plastics [4, 5]. In the paper [6] was performed simulation of a hole-flanging to investigate the effect of various process parameters. In paper [7] a combined process of hole flanging and flange upsetting was proposed. Both elastic-plastic Finite Element Method and experiments were employed to analyze the process. The finite element results were validated by experimental results. In paper [8] the geometrical parameters of the flange were analysed. Conventional hole-flanging process of 0.8 mm thin sheet metal was used. Both the initial hole diameter and the clearance-thickness ratio were changed during the process. Good agreement between numerical simulations and experiments was investigated.

The classic hole-flanging process is increasingly being replaced by the thermoforming process. The thermal drilling technology is increasingly used for the edge trimming of holes and its unquestionable advantage is to perform this process without chips. The conical tool made of sintered carbides rotates at a high speed and at the same time axially presses on the surface of treated material causing the friction phenomena. Thermal drilling technology is applicable to processing of different types of materials e.g. iron, aluminum, copper and their alloys. This process is an alternative to the conventional method of edge trimming of holes, which is usually carried out using of mechanical or hydraulically presses. The prepared holes may be subjected to threading process. It allows to eliminate of application the welded nuts in the process of design and manufacture. These types solutions are
used in various industrial sectors such as automotive, production energy, namely everywhere, where is required to obtain the high-strength bolted connections without additional connecting elements [9, 10]. An important advantage of thermal drilling technology is the ability to perform edge trimming of holes not only in sheets of metal but also in the thin-walled hollow sections. Another advantage is the possibility of using one type of tool for edge trimming in the different materials. Additionally, the system of quick-change tools undoubtedly streamlines the production process and consequently increases production capacity. Holes obtained during the thermal drilling process may be utilized as port for welded, soldered or glued joints. Thermal drilling technology, may be used to making holes in the coatings [11-14]. Process described in this paper allows to reduce of the structure mass and additionally allows to elimination countering elements, especially in case when their assembly is hindered or impossible.

In the relatively few available publications it is on the same tools to thermal drilling processes. This paper focused on microstructure, chemical composition and selected mechanical properties of material used in the produce of tools used in thermal drilling technology. Additionally, the attention was given to influence of tools operation on their wear resistance.

2. Research methodology

2.1. Flowdrill process
During the study, holes into S235 steel sheet with thickness of 2 mm were made. On sheet surface the protective paste increasing tool life was applied, and then series of holes were made. Drilling process was conducted with rotation speed equal to 3000 rpm and was selected on the basis of manufacturer's data and preliminary tests. Hole drilling was carried out using a JET JMD-18VS drilling-milling machine (Figure 1a) equipped with the head for thermal drilling process (Flowdrill). The head consists of tool-chuck with cooling disk, collet and what is most important - drill tool for thermal drilling process (Figure 1b). In the first step of process, tip of conical part of drill (at constant rotation speed) is in contact with the surface of treated material (Figure 2a), which deforms due to the heat caused by friction (Figure 2b). In the next step of process, cone of drill causes pushing of treated material in two directions. Inside profile arises the sleeve (Figure 2c).

![Figure 1. The test stand for thermal drilling process: a) JET JMD-18V drilling-milling machine, b) tool for thermal drilling process.](image)

Afterwards, the pressure force of tools on surface is reduced. In the same time, the feed rate, related with entering drill in material is increased. After passing of drill through the material, the cylindrical section of tool gives shape of sleeve (Figure 2d). Flash, which established during the process is cut off by the flange-forming section of drill (Figure 2e). In the final step, tool is withdrawn from formed hole and finally treated material is subjected to the self-cooling (Figure 2f).
2.2. Macro- and microscopic observations
To analyse microstructure of tool material and its surface condition after thermal drilling process and to determine the type of fracture after damage of tools scanning electron microscope (SEM) Vega 5135 from Tescan was used. After thermal drilling process, specimens were cut out from tool and were polished using abrasive paper of decreasing granularity and finished using Al$_2$O$_3$ and next to reveal microstructure a 2% Nital was used. Based on microstructure of tool material, the quantitative analysis of carbides was made. Macroscopic studies also included measurements of surface roughness before and after process. These measurements were carried out using surface roughness tester from Hommelwerke.

2.3. Hardness evaluation and chemical composition
Hardness in cross-section of tool before and after Flowdrill process was measured by the use of HPO-250 Vickers-Brinell hardness tester. Indentation load of 294 N was used in this study.

Chemical composition of tool material used in this study was investigated using scanning electron microscope equipped with PTG Prism Si(Li) energy dispersive X-ray spectrometer (EDS). Point analysis were performed.

3. Research results
3.1. Macroscopic research results
In this study both new and used tools were used. Based on them it was possible to compare the condition of surface layer before and after thermal drilling process. On worn tools, oxides and slightly-melted surface were observed. These effects were associated with increased temperature of tool during process. It was found near twofold increase Ra parameter of roughness on tools after thermal drilling process in relation to the new tools. New tools were characterized by a surface roughness Ra=0.63 while the roughness after damage were contained in the range from Ra=0.94 to Ra=1.18.

During surfaces fracture analysis of tools, the presence of beach marks was revealed, which indicated on the fatigue type of crack. The initiation places of these cracks was located on the outer surface of tool and then spread into its centre, where presence the brittle crack, characteristic for sintered material was observed. Kinetics of tool operation and its geometry indicates that during thermal drilling may occur fatigue cracks. Examples of this type of fracture was shown in Figure 3.
3.2. **Microstructure analysis**

All tools used during the tests were characterized by microstructure typical for sintered carbide, which consisting of carbide particles in the metal matrix. Different types of carbide were observed, but in all cases they had an irregular shape and sharp edges, and their dimension does not exceed size of 7 µm. Microstructure of the used material was shown in Figure 4. SEM image was taken by method of backscattered electrons (BSE), therefore carbide particles containing elements with greater atomic number, were seen as light areas while those with lower atomic number were seen as darker. Drill tools used in this study were characterized by different durability, but these differences were not significant and seems to that depend on the presence and amount of porosity as well as homogeneity of the produced sintered material. This homogeneity, most often results from adequate preparation of powder mixture prior to sintering process.
Places of agglomeration of the carbide particles of various types were observed. These agglomerations may have been affect on premature cracking of tools due to the differences of hardness between different carbide types. In Figure 5 was shown porosity, which presence also may have been a significant effect on tool durability. The porosity was estimated to be about 4%.

3.3. Hardness results
In Table 1 was shown the results of hardness measurements in respect to the distance from the tip of tool. The hardness was measured in the tool axis. The presented results are the average values from 10 measurements. On the basis of measurements was found that there is a slight decrease in hardness values at the surface of tool. This is associated with changes in microstructure of sintered carbides, which was caused by impact of heat emitted during thermal drilling process. However, hardness reduction does not significantly affected on tool properties. Other hardness values are very close to each other.

| Distance from tip of tool [mm] | Hardness [HV30] |
|-------------------------------|-----------------|
| 2                             | 1493            |
| 5                             | 1549            |
| 8                             | 1515            |
| 12                            | 1504            |
| 15                            | 1515            |
| 18                            | 1504            |

3.4. Chemical composition results
The results of quantitative analysis of the chemical composition the sintered tool material was shown in Figure 6. As shown in the tables at the Figure, in addition to carbon, also tungsten, titanium and cobalt presence were found.

Very good mechanical properties and wear resistance of the used sintered carbide tools were obtained through very hard carbides formed by these metals. Titanium carbide (TiC) and tungsten
carbide (WC) applied to produce this tool are simultaneously high-melting materials which allows to carried out the thermal drilling process.

4. Conclusions

An important role in the process of thermal drilling plays a high temperature in which this process takes place. It can contribute in damage the surface layer of the tool and changing of microstructure of the material (eg. increased roughness). It may also adversely affect the molded shape of the edges and alter the microstructure of the material in the contact zone of the bit-hot material. Changes in geometry or surface roughness may affect the quality of the product being manufactured. Additionally surface defects during operation cannot be often perceived until the tool breakage. During the tests, the surface roughness of the tool was significantly increased during operation as well as slight changes in hardness that do not affect the process was found. In addition, porosity was found in most of the tools tested.

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