EXPERIMENTAL ASSESSMENT OF CHANGES IN THE STRUCTURE OF FOOD-GRADE ANTI-CORROSION STEEL DUE TO THE USE OF FLOWDRILL TECHNOLOGY

JOZEF MASCENIK[1]

[1]Technical University of Kosice, Faculty of Manufacturing Technologies with a seat in Presov, Slovak republic

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e-mail: jozef.mascenik@tuke.sk

Machining technologies are constantly evolving in line with new material development strategies, with further advances in cutting tools accelerating these changes even further. Growing demands for increased productivity and production efficiency have led us to today's advanced level of technology. Recently, steel structures made of thin sheets and strips, which are processed by bending, three-dimensional forming or pressing, often in combination with technologies such as ribbing, have been increasingly used. Open and closed rolled profiles are increasingly being replaced by more economical and lighter sheet metal strip materials, which provide similar or even higher strength at a significantly lower weight. Flowdrill technology is often used when joining light sheet metal profiles in a demountable manner, which enables the creation of a cylindrical surface necessary for the subsequent shaping of the thread. Flowdrill thermal drilling technology represents an innovative and forward-looking method of producing precise cylindrical housings in thin-walled materials such as sheets, profiles of various shapes and pipes. This technology uses frictional heat, which is generated by a combination of high tool speeds and axial force acting on the workpiece. Frictional heat causes the material to soften, allowing the tool to smoothly penetrate the workpiece and form a sleeve from the displaced material [Rimar 2023]. This process inspired experimental measurements aimed at analyzing the influence of technology parameters on the material. The aim of the experiments was to investigate structural changes in food-grade anti-corrosion steel EN ISO X10CrNi18-8 (17241) as a result of Flowdrill thermal drilling, by analyzing the state of the material before and after the application of this technology. The results of these measurements will bring valuable knowledge to technologists, which will help them choose suitable materials and drilling technologies in practice.

KEYWORDS

Stainless steel, Flowdrill technology, drilling, microstructure

1 INTRODUCTION

Demountable joints, especially bolted joints, are among the most common methods of joining parts across various industries. At the same time, threaded connections often allow the transmission of rotary or sliding motion. The production of threads includes two basic types, namely internal and external threads. From a technological point of view, threads are produced using manual machining, turning, milling, cutting with taps or thread-cutting heads, as well as forming. These processes can be divided into two main categories, which are fundamentally different - the production of threads by chip machining (cutting) and the production by forming (rolling).

1.1 Thread cut

Cutting is one of the traditional methods of thread production. In this process, material is gradually removed from the cylindrical or conical blank, creating a thread of the desired shape and profile, for example, triangular or trapezoidal. Threads can be cut manually or by machine, while the choice of method and tools depends on the type of thread. The most common method in engineering practice is thread cutting with taps, which is used primarily for threads of small and medium diameters [Straka 2020].

Tap sets are used for manual thread cutting in blind holes longer than 1.5 times the thread diameter. For normal metric threads, the set contains three taps, while two are sufficient for fine threads. The first two taps gradually undercut the thread, while the third one calibrates it. The share of the removed material is divided as follows: the first tap takes 60%, the second 30% and the third 10%. Each tap has a cutting taper, which is longer in the first two.

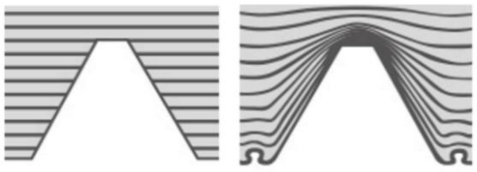
Evaluation of the threading process and tool suitability focuses on torque magnitude, wear, tool durability and life, shape and chip removal, as well as the accuracy and quality of the threaded hole [Mascenik 2023]. The disadvantage of this method is poor removal of chips. Optimal working conditions include the correct selection of the tool, suitable cutting speed, use of an effective cutting fluid, precise clamping of the tool and the workpiece, and thorough maintenance of the tools. These factors fundamentally affect the quality of the process and the resulting thread.

1.2 Rolled (shaped) thread

Forming of threads by rolling belongs to the methods of transverse forged rolling and is used in the surface forming of cylindrical surfaces. With this technology, threads, lubrication grooves, grooves on shafts and similar elements can be created cold. The type of tooling used depends on the movement during forming – reciprocating motion uses flat tools, while rotary motion uses disc tools [Husar 2019]. The forming process uses a deformation wedge whose height and width vary according to a certain function, usually a cubic parabola [Krenicky 2022]. In order for the deformation to be properly realized, it is necessary to follow several principles when designing the caliber:

- The volume of metal in the gauge must remain constant throughout the rolling process.
- The profile of the deforming wedge must be designed to take into account the gradual withdrawal of the formed metal.
- Reshaping must be done in small steps to avoid breaking the cohesion of the material [Coranic 2021].

Forming internal threads of smaller diameters can also be performed with a specially adapted tap. Thread forming has similarities with hole forming, but during this process the temperature of the material does not rise significantly, as it is a cold technology. Unlike thread cutting, the internal structure of the material is not disturbed, which increases the strength of the resulting thread. Figure 1 shows the difference between threads created by cutting and forming.



Grain structure during thread cutting

Grain structure during thread rolling

Figure 1. Chipping and chipless external thread production

1.3 *Thermal drilling - FLOWDRILL*

Flowdrill thermal drilling technology is an innovative way of producing precise cylindrical sleeves in thin-walled materials such as sheet metal, profiles or pipes for the creation of detachable joints. The principle of this technology is based on hot forming. A rotating tool, called a forming drill, generates frictional heat by friction between the tool and the workpiece under the action of an axial force [Husar 2022]. As a result of reaching a temperature of 600 to 800 °C, the material in the machining area softens, allowing the tool to pass through the material and form the desired case shape. During the process, a collar is formed, which arises as a result of the material flowing. Depending on the tool used, the collar can be modified into a "collar" shape or removed flush with the surface of the blank. The Flowdrill itself is a polygonal conical tool made of tungsten carbide, which ensures high hardness and resistance to high temperatures. The working part of the drill consists of a point tip, a conical segment and a cylindrical body. The Flowdrill tool also includes a cylindrical collar, an alignment milling machine and a cylindrical shank for clamping in a collet.

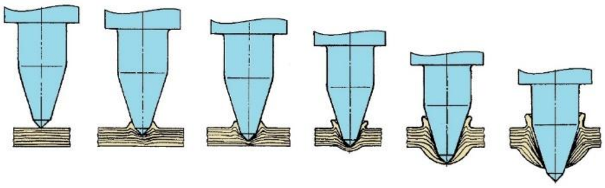


Figure 2. Phases of thermal drilling

At the beginning of the thermal drilling process, there is point contact and at the same time the generation of initial heat as a result of the axial force and rotation of the tool. Gradually, a simultaneous passage of material occurs (flow of material upwards and then downwards). By passing the tool through the entire cross-section of the workpiece (both the melted material and the bottom), a precise casing is formed (Fig. 2). After the desired casing shape is completed, the Flowdrill tool is used to cut the collar and then pull the rotating tool up out of the cylindrical hole. After creating the desired shape of the case, it is possible to make a thread by forming or cutting [Coranic 2018].

Flowdrill tool is made with specially developed carbide. The latter maintains its strength at high temperatures but is sensitive to temperature changes (stresses). It is also advisable to avoid local cooling [Mascenik 2013]. Flowdrill tools cannot withstand high mechanical shocks. It is necessary to prevent the impact of the tool on the workpiece, its falling, and to avoid welded areas (seams, especially for pipes and profiles). Avoid radial forces acting on the tool. Speed stability is also very important. Rapid release of twisting (torsional) load caused by e.g. very fast passage through the material (or fast feed) can cause fatigue of the tool material. A similar case can occur if the initial pressure (axial force) is too large. Never drill an unfinished hole, as this risks drawing in and stopping the cone (tip) in the hole. Vibration and misalignment of the machine can cause the tool to break. The temperature of the tool should not exceed a dark red color. The speed and axial force should be set optimally so that the temperature does not exceed 700°C (indicated as a dark red color).

2 MATERIAL AND CONDITIONS OF SAMPLE CREATION

In the experimental measurements, samples from food-grade anti-corrosion steel EN ISO X10CrNi18-8 (17 241) were used. A Flowdrill Flott P23 machine tool with a power of 0.7 kW and a tungsten drill with a diameter of ϕ9.2 of the short type were used for the production of the cases in the samples. Drilling paste FDKS was used as a lubricant, which creates a protective film between the tool and the sheet metal. Samples made by Flowdrill technology were subjected to a general metallurgical evaluation, with an emphasis on the analysis of metallurgical changes in the microstructure of the base material caused by the process [Duhancik 2024]. Figure 3 shows the fabricated samples ready to be cut through holes and further prepared for microscopic analysis.

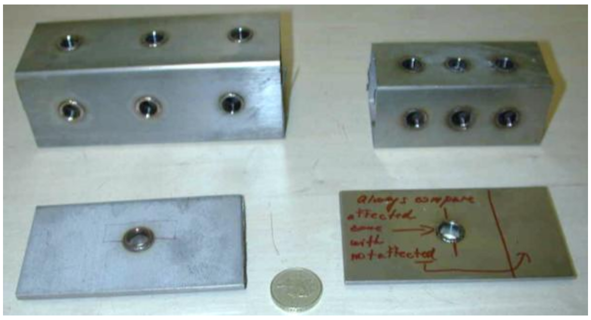


Figure 3. Drilled and cut samples subjected to research

Flowdrill holes cut through the center of the hole have a diameter of 10 mm and an approximately 5 mm stamped tail on the outside of the holes (Figure 4).

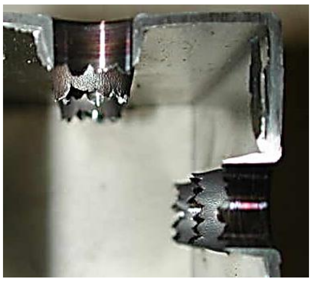


Figure 4. Sample cut through the center of the hole

2.1 *Metallographic analysis*

The selected sample was processed by standard metallographic procedures, using a water-cooled grinding wheel to finish the surface to a fineness of 1 micron. Grinding precision is crucial for microscopic analysis, so the process ends with a thorough polishing. Polishing serves to remove the grooves created by sanding, thus ensuring a smooth surface for further examination. The sample (Figure 5) was polished on a Buehler Metaserv Motopol 8 using the automated polishing mode.

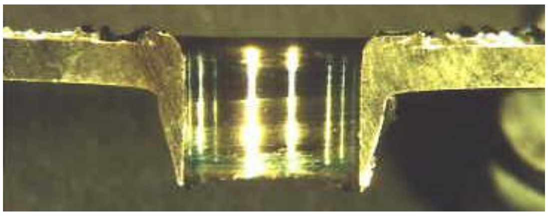


Figure 5. Sample prepared for microscopic analysis

After polishing, the sample was electrolytically etched for 10 seconds in a 10% solution of nitric acid in methyl alcohol at a voltage of 6V DC and then examined under a metallurgical microscope. The microstructure of the base material near the Flowdrill holes and their HAZs showed a typical austenitic stainless single-phase structure with pure polyhedral and twinned austenitic grains. This structure is characteristic of materials that have been subjected to high temperature treatment and repeatedly cooled in a cooling medium (water at approximately 1050°C). The sample contained a small amount of delta ferrite (less than 1%), which is common for this type of material. Grain edges were only minimally exposed by etching, indicating a very low carbon content and negligible presence of carbides in the heat-affected zone. This is a consequence of the temperature effect of the Flowdrill thermal drilling process (Figure 6).

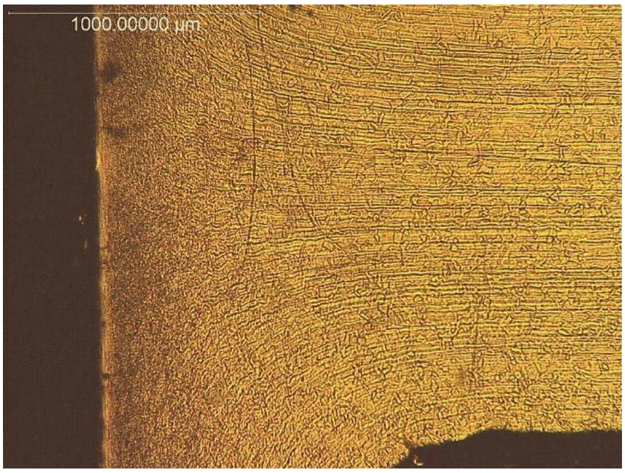


Figure 6. Photograph of the microstructure around the Flowdrill hole

A Nikon Optiphot and Olympus Vanox metallurgical microscope, equipped with a digital camera and an eyepiece, was used to capture the microstructure. Changes in the structure appear gradually, with the most pronounced within a range of up to 3 mm from the edge of the hole. To a lesser extent, they continue up to a distance of 8 mm from the edge of the hole. These gradual changes are documented in photographs taken using the mentioned microscope (see Fig. 7). The samples were etched electrolytically in a 10% solution of nitric acid in methyl alcohol at a voltage of 6 V DC.

Figure 7. Photograph of the microstructure of the base material containing polyhedral grains of austenite with a small amount of delta ferrite (Microhardness: 200HV0.5)

Figure 8. Microstructure photograph illustrating the low-temperature treated zone between the hole surface and the base material (Microhardness: 250HV0.5).

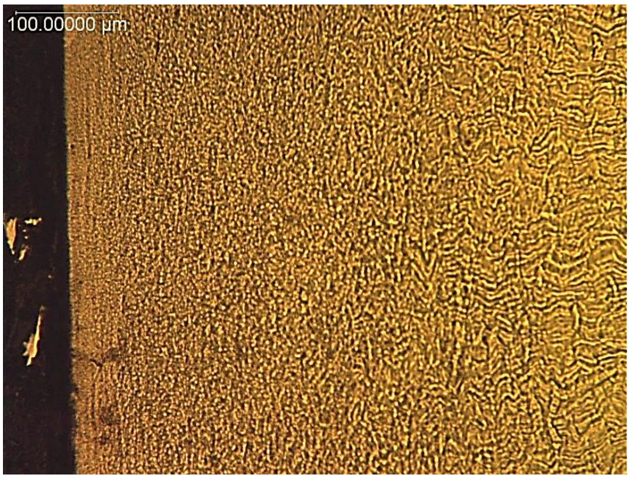


Figure 9. Photograph illustrating refined microstructures on the hole surface (Microhardness: 300HV0.5)

In the photographs (Figs. 7, 8 and 9) the elongated grains are clearly visible, showing a mottled appearance. These changes are caused by the heat and pressure exerted during the Flowdrill thermal drilling process [Mascenik 2011]. Heat generated by friction and pressure cause transformations in the microstructure of the material [Miglierini 2006], leading to the formation of these characteristic grains.

3 ANALYSIS OF MICROHARDNESS

The change in hardness was measured by the Vickers hardness test method. Microhardness tests were performed along the hole profile, which extended from the surface of the hole through the heat affected zone to the base material, using a load of 500g. Microhardness was determined using a Buehler 1600 Micromet automatic microhardness measuring device. Figure 10 clearly shows how the hardness increased towards the holes.

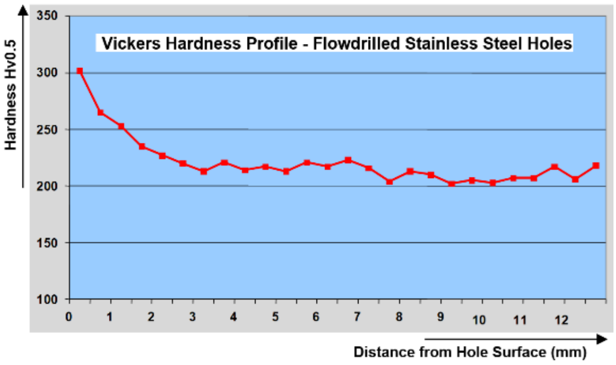


Figure 10. Dependence of the hardness HV 0.5 on the distance from the hole surface

4 CONCLUSIONS

The investigated material had a strong but brittle martensitic structure formed in the heat-affected zones around the Flowdrill holes as a result of phase transformation cooling at the high temperatures generated during the process. There are other metallurgical processes in which austenitic stainless-steel changes its properties when heat is applied to the steel [Vahovsky 2019]. These processes refer to the deposition of chromium carbides on the grain edges, which can cause serious degradation of corrosion resistance. The Flowdrill processes caused the microstructure of the base material to improve and deform while strengthening the austenitic grain up to a depth of 3 mm around the surface of the hole. Thermal effects on the microstructure are minimal and no carbide deposits are formed on the edges of grains and heat-treated zones, which could, on the contrary, cause corrosion of this type of material.

The main metallurgical concern during thermal processes for this type of material is the deposition of chromium carbide on the grain edges. This happens at medium temperatures from 650°C to 900°C and is a frequent phenomenon, e.g. in the heat-affected zone of welds that apply to this temperature range. The formation of granular carbide phases locally exposes the grain edge of chromium, which causes the material to be susceptible to pitting corrosion. The microstructure of the material does not contain any titanium or niobium carbide. It is also unlikely that the material is very low carbon, as the absence of chromium carbide grain edges in the heat affected zone can only be attributed to the rapid heating and cooling produced by Flowdrill processes, which minimizes the deposition of chromium carbides.

As our research has found no significant detrimental metallurgical effects of Flowdrill processes on the material, the loss of corrosion resistance around and inside holes drilled with Flowdrill thermal drilling is of interest. Considering this, we could recommend these specific corrosion tests that confirmed our metallographic findings to consumers of this type of material.

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CONTACTS

Assoc. Prof. Jozef Mascenik, PhD.
Technical University of Kosice
Faculty of Manufacturing Technologies with a seat in Presov
Department of Design and Monitoring of Technical Systems
Bayerova 1, Presov, 080 01, Slovak Republic
+421 51 772 6337, jozef.mascenik@tuke.sk, www.tuke.sk