DOI: 10.21062/mft.2023.078 © 2023 Manufacturing Technology. All rights reserved. http://www.journalmt.com

Optimization of Threads Production on Thin – Walled Castings

Dana Stančeková (0000-0003-0713-8750)[1], Jozef Mrázik (0000-0002-1793-6185)[1], Anna Rudawska (0000-0003-3592-8047)[2], Miroslava Ťavodová (0000-0002-7376-4189)[3], Izabela Miturska-Barańska (0000-0003-4140-4768)[2], Daniela Sršníková[1], Miroslav Špiriak[1]
[1]Faculty of Mechanical Engineering, University of Žilina, Univerzitná 1, 010 26, Žilina. Slovak Republic. E-mail: dana.stancekova@fstroj.uniza.sk, jozef.mrazik@fstroj.uniza.sk, daniela.srsnikova@fstroj.uniza.sk
[2]Faculty of Mechanical Engineering, Lublin University of Technology, Nadbystrzycka 36, 20-618 Lublin, PL, a.rudawska@pollub.pl; i.miturska@pollub.pl
[3]Faculty of Technology, Technical University in Zvolen, Študentská 26, 960 53. Slovak Republic. E-mail: tavodova@tuzvo.sk

This study focuses on the analysis and solution of thread production in thin-walled profiles. It explores three different threading technologies, including cutting, forming, and extrusion. The issue of a screw joint in a thin-walled component is complex due to the stiffness of the joint and the short length of the thread. Hence, the careful choice of a suitable manufacturing process for producing inner threads in thin-walled components holds significant importance. The study entails monitoring the hardening of surface layers of materials after thread production, in conjunction with the acquisition of microstructure images of the experimental material. The outcome is a comparative evaluation of different individual thread production technologies.

Keywords: thread cutting, thread forming, thread pressing, thin-walled profile

1 Introduction

Throughout history, inner threads and screws have been key mechanical components that have contributed significantly to the evolution of technology and equipment [1]. Unquestionably, the use of threads is the most common way to connect components in numerous industries. Furthermore, there are various thread applications available that allow for the smooth transfer of rotational or translational movements [2]. Threaded connections are widely used in technical construction, with prominent applications in the aerospace, medical, and dental industries [1,3,4]. Taking all of this into account, the industry has developed several models that incorporate numerous aspects such as thread pitch, profiles, and geometries [1, 3]. Screwed joints are frequently used due to their inherent advantages in terms of both installation and disassembly, which allow for faster maintenance procedures while maintaining joint integrity [5,6,7,8]. Despite these advantages, screw joints are frequently used as key components in equipment subjected to variable loads. This emphasises the significance of the fatigue resistance inherent in the joints for the reliability of screw-jointed machinery [9].

When considering threaded joints, where the screw is directly threaded into the component material, it is clear how important the material strength of the component is to the number of threads needed to keep the screw from shearing off [10].

Currently, almost all engineering companies are equipped with production machinery that includes thread production. Despite its underappreciation, this procedure is recognised as one of the most technologically difficult machining processes. The major goal of manufacturers is to develop a manufacturing process that is highly effective, accurate, and capable of generating high-quality products, hence ensuring their market competitiveness.

To produce threads in thin sheets, various technologies, such as thread cutting, thread forming, and thread extrusion can be employed.

Thread cutting is a chip-removal machining process in which the thread is gradually cut by the cutting edges of a tap, removing a significant volume of chips during the threading process [11,12].

Thread forming is a cold plastic deformation process that produces threads with enhanced mechanical properties, optimal microstructure, high surface quality, and higher productivity [13,14,15]. This process results in faster, higher-quality, longer-lasting performance, and more cost-effective production. This type of manufacturing can be carried out using a variety of specialised equipment employing different technological methods [15,16,17].

Disassembleable and high-load-bearing screw joints can be difficult to install in thin-walled components, particularly hollow profiles. Flow drilling followed by thread-forming technology is an economically and technically appealing manufacturing option. During flow drilling, a rapidly rotating carbide conical tool creates a sleeve, and in the subsequent production process, a highly resilient inner thread can be fabricated [18,19].

The primary aim of every manufacturer is to optimise their manufacturing process in terms of efficiency, accuracy, and quality, thereby producing a product that is competitive in the market.

This study aims to create inner, right-hand metric threads labelled as M6x1 within thin-walled profiles using three distinct technologies (cutting, extrusion, and forming) and then perform a variety of measurements and evaluations to reveal the benefits and drawbacks of each individual technology.

The decision to address this topic emerges from the fact that in most manufacturing companies, threading process technology is underestimated, resulting in frequent tool damage and substandard thread quality. The research will help us understand and explain which of the selected technologies for the production of M6x1 threads in 5mm thick sheets is the most suitable and at the same time economically optimal.

2 Experiment Description

The experimental material was S235JR steel, which belongs to the group of structural steels manufactured following the international standard STN EN 10025. These particular steels are characterized as being low-carbon, non-alloy, and high-quality variants suitable for applications in environments with diminished atmospheric temperatures, specifically below -20°C. Notably, they possess a minimum yield strength of 235 MPa [20].

Thin-walled profiles made from S235 steel are among the most employed materials in manufacturing. To meet operational demands, the profiles were cut to dimensions that ensure enhanced manoeuvrability, as shown in Figure 1. The thin-walled castings utilized in this study fall within the category of welded closed profiles with a square cross-section. These profiles are manufactured following the EN 10219 standard. The samples employed for the study possess dimensions of *a* x *b* x *t* = 40 x 40 x 5 [mm] with a length of 170 mm, effectively enhancing their handling capabilities.

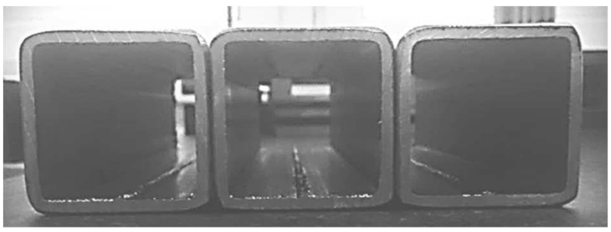


Fig. 1 *Samples - Thin-walled castings*

Tools made from hard alloy materials, sourced from reputable manufacturers, were employed. The drilling operations were carried out on a 3-axis CNC machining center bearing the DECKEL MAHO DMU 80E brand. Pre-threading was accomplished using spiral drill bits manufactured by WALTER, as shown in Figure 2. For the creation of M6x1 threads through cutting, ø5 mm drills were implemented. In the case of thread forming, ø5.55 mm drill bits were employed following the specifications outlined in the DIN 13-50 standard. After the initial hole pre-drilling phase, the thread manufacturing process commenced, employing M6 cutting and forming taps from the HOFFMANN brand, as de

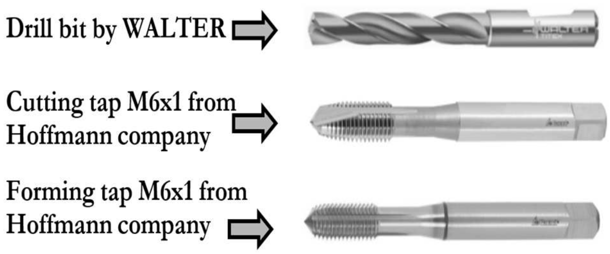


Fig. 2 *Milling, drilling, and tapping tools with description [21,22]*

In the thermal drilling process, the prescribed tool known as the flow drill was employed, along with a paste to facilitate a smoother tool-material transition, as depicted in Figure 3.

Fig. 3 *Tool for thermal drilling, also known as FLOW DRILL*

To obtain the cutting parameters of the drilling tools, a pivotal role was played by the specialized WALTER software, denoted as GPS. This software enables the exact derivation of cutting parameters, meticulously factoring in variables like material composition, drilling depth, and stability conditions through its capabilities. The specific parameters are listed in Table 1. The values of revolutions for thread cutting were precisely defined at 180 min^{-1}, while for the thread-forming process, a consistent velocity of 250 min^{-1} was employed.

Tab. 1 *Cutting parameters of WALTER drilling tools [21]*

Drill Bit	Ø 5 mm	Ø 5.5 mm
Cutting speed [m.min^{-1}]	132	132
Spindle revolutions[min^{-1}]	8400	7560
Feed [mm]	0.148	0.158

2.1 Thread Manufacturing Technique for Thin-Walled Profiles

The techniques employed for producing internal threads in this study, specifically cutting and forming techniques, are currently regarded as the most commonly employed and widespread approaches. The thermal drilling technology, which involves pre-drilling holes using the flow-drill tool, is currently less utilized due to its replacement by more advanced and rapid drilling tools employed in CNC machining centres.

Before commencing the actual machining procedure, 3D models were generated using SolidWorks software to depict the thin-walled profiles post-threading, alongside sectional models (Fig. 4). These models proved to be invaluable aids during the preliminary design stages and played a pivotal role in guiding the machining process.

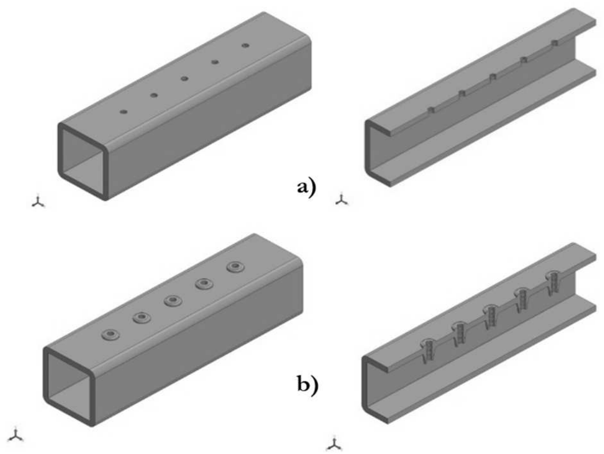


Fig. 4 *a) Thin-walled profile after threading + half-section cut; b) Thin-walled profile after thermal drilling + half-section cut*

As previously indicated, the production of internal threads encompassed the initial step of pre-drilling holes through the application of hard alloy drill bits and the deployment of the flow-drill tool, integral to thermal drilling. For the cutting of M6x1 threads (with a standard pitch), a normalized hole of 5 mm in diameter was drilled. The procedure of forming M6x1 threads necessitated pre-drilled holes with a diameter of 5.55 mm. Both drilling and threading operations were carried out utilizing the machining software, Heidenhain iTNC 530, as well as its preceding version, iTNC 430.

3 Evaluation of Thread Quality

In the comprehensive control of thread parameters, callipers are commonly employed in both regular serial and mass production. A roller calliper is specifically employed for examining smaller diameters. To facilitate the inspection, individual threads were carefully cleaned to prevent any scoring of the roller calliper during the screwing process. The roller calliper consists of two sides – the correct and the incorrect - distinguished by a red ring. When the calliper size is correct, the incorrect side of the calliper cannot enter the hole during the screwing operation. Comprehensive controls were meticulously performed for all three of the utilized techniques. The use of the roller calliper for thread control is depicted in Figure 5. Roller callipers showcase impressive precision, effectively mitigating significant issues during the control process. However, with the utilization of more precise thread control methods, deviations from tolerance may be identified. This phenomenon is further explored in the subsequent sections.

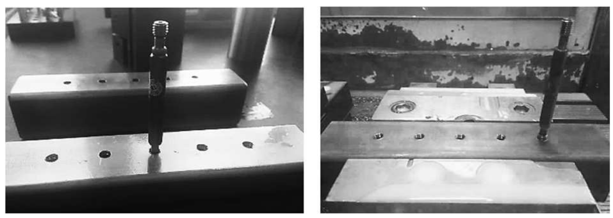


Fig. 5 *Detail of M6x1 thread inspection with a correct and incorrect side of roller calliper*

3.1 Metallographic Analysis of the Base Material

Figure 6 displays the microstructure of the base material, clearly illustrating that the microstructure comprises polyhedral ferrite grains with only a minor content of pearlitic grains, consistent with the chemical composition (0.17% C).

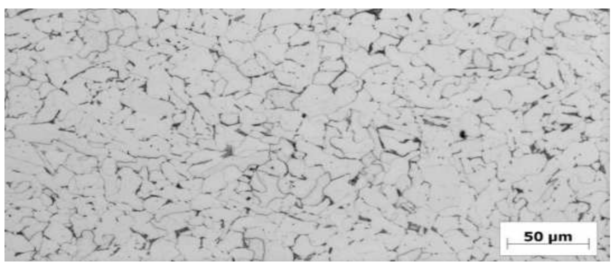


Fig. 6 *Microstructure of the base material of experimental samples, etchant 1% Nital*

3.2 Microhardness Measurement

The microhardness measurements adhered to a procedural method standardized under the STN EN ISO 6507-1 norm. The Zwick Roell ZHμ microhardness tester was utilized for measuring the test samples. The HV 0.2 method was used, signifying an applied load of 0.2 kp. The diamond indenter, featuring a pyramidal angle of 136°, was utilized for these measurements. This microhardness measurement encompassed three distinct stages and involved a total of six samples. These samples were methodically categorized based on the specific threading technique employed. These categories encompassed samples featuring threads produced through cutting, those with formed threads, and lastly, those with threads produced by the thermal drilling process, which involved machining into pre-drilled holes.

3.3 Microhardness of Threads Produced by Cutting

Figure 7 provides a microhardness measurement detail, (transverse, from the crest, and at the root of the thread), along with individual imprints in the form of a regular tetrahedral pyramid. The image was captured using the CLEMEX software.

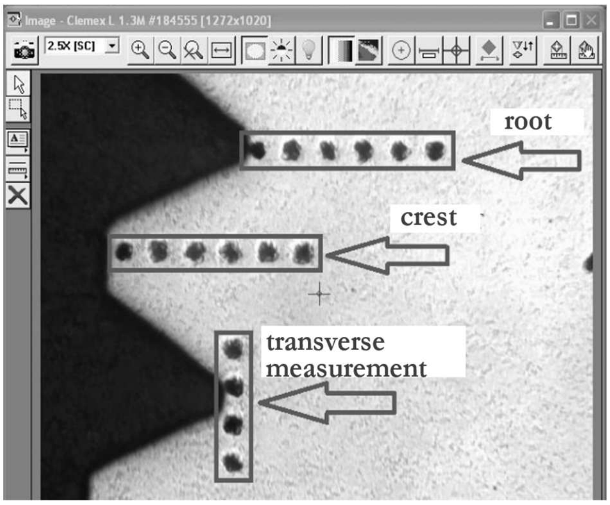


Fig. 7 *Detail of imprints during the measurement of the thread profile produced by cutting*

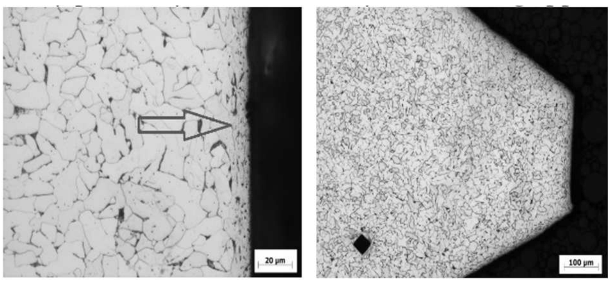


Fig. 8 *Images of the microstructure of threads produced by cutting*

Figure 8 illustrates that within the context of thread-cutting technology, characterized by material removal, there is no significant increase in plastic deformation. This leads to a relatively small and unobtrusive plastic zone, with the thickness of the extensively plastically transformed layer measuring approximately 10μm.

3.4 Comparison of Hardness Progression at the Root and Crest of Cut Threads

As a first step, we will evaluate the samples with threads produced using the cutting technology. The graph presented in Figure 9 compares the hardening progression of the material at the root and crest of the thread profile. The graph indicates that differences in surface hardening are marginal. Both curves display a comparable pattern, where the hardening effect extends to similar depths. The extent of plastic deformation is nearly identical at both measuring points (root and crest of the thread profile), resulting in negligible differences.

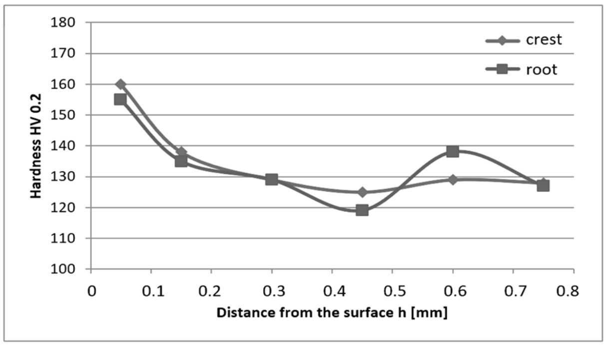


Fig. 9 *Microhardness profile from the crest of the thread profile - cutting*

3.5 Microhardness of Threads Produced by Forming

Figure 10 provides a microhardness measurement detail (transverse, from the crest, and at the root of the thread).

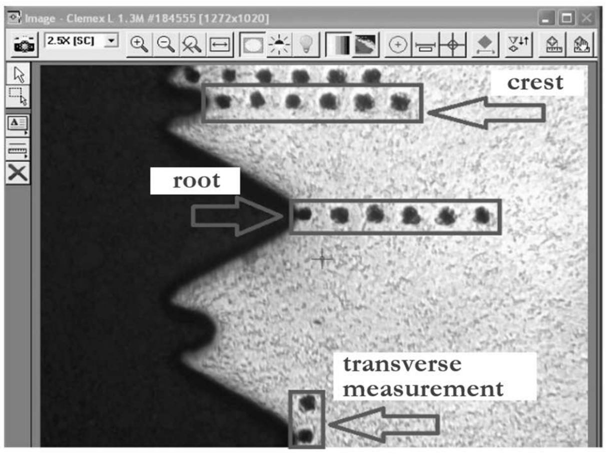


Fig. 10 *Detail of imprints during the measurement of the formed thread profile*

Threads produced by forming display superior quality and strength when contrasted with their thread-cut counterparts. This enhancement arises from the surface hardening brought about by material densification, which effectively safeguards the integrity of the fibers within the thread profile from disruption. This observation is confirmed by images taken of the thread profile edge. In Figure 11, it can be observed that the plastic zone extends to the surface and operates unilaterally. The thickness of the substantially plastically transformed layer measures approximately 40μm. The fibers in the thread profile undergo uniform deformation.

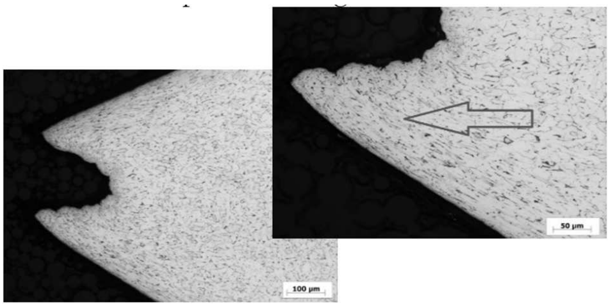


Fig. 11 *Images of microstructures of threads produced by forming*

3.6 Comparison of Hardening Progression at the Root and Crest - Forming

In this subsection, our focus is on comparing the hardening progression at the root and crest of the thread profile for thread-forming technology. Figure 12 illustrates that both curves follow a similar trend. The discrepancy becomes evident in the HV0.2 hardness values. In the root region of the thread profile, the measured maximum hardness value exceeded 210 HV0.2, whereas, at the thread crest, it reached 184 HV0.2. Within the root region of the thread profile, more significant material overheating occurred compared to the crest of the thread profile, resulting in more intense plastic deformation due to variations in material plastic flow and an increase in hardness values.

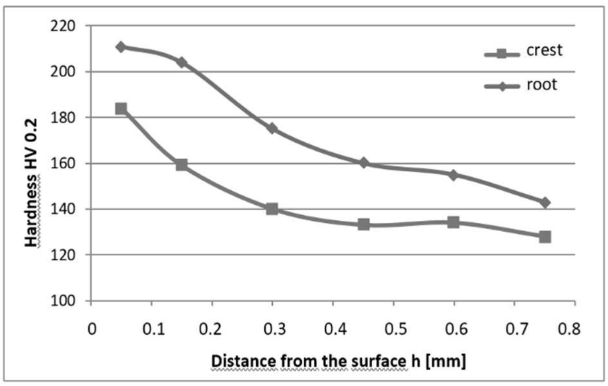


Fig. 12 *Comparison of the hardening progression at the root and crest of the thread using the forming technology*

3.7 Microhardness of Extruded Threads

Figure 13 presents a microhardness measurement detail (transverse, from the crest, and at the root of the thread).

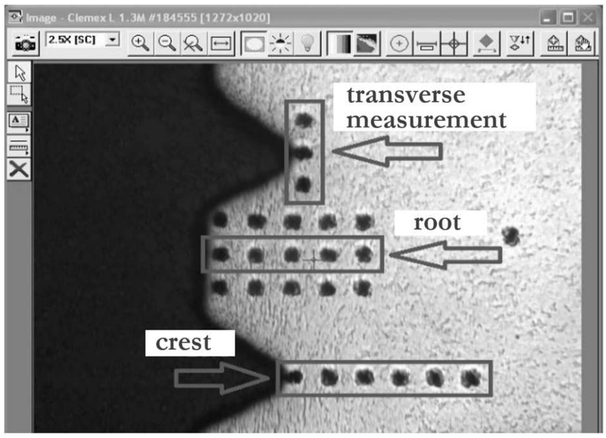


Fig. 13 *Detail of imprints during the measurement of the thread profile produced by extrusion.*

As demonstrated in Figure 14 for the extrusion technology, specifically thermal drilling, a significant grain refinement occurs near the edge of the thread profile. This phenomenon is attributed to plastic deformation combined with significant heat generation and subsequent rapid cooling, resulting in increased surface hardness. The thickness of the considerably plastically transformed layer measures approximately 50 μm.

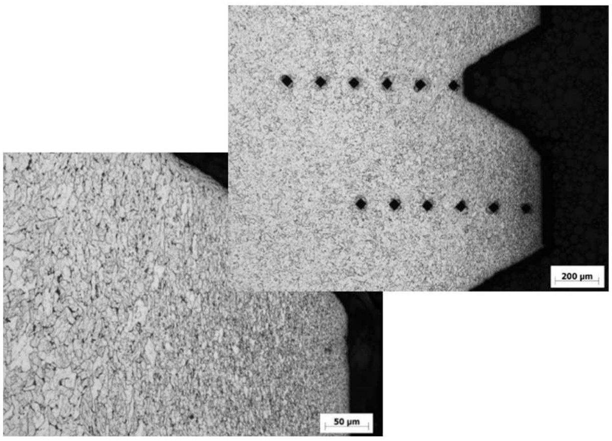


Fig. 14 *Microstructure images of threads produced by extrusion*

3.8 Comparison of Hardening Progression at the Root and Crest - Extrusion

The third technology employed for thread production is extrusion. Figure 15 illustrates a comparison of the hardening progression at the root and crest of the thread. The graph clearly shows that the profiles of both curves exhibit different shapes and diverge in the measured HV0.2 hardness values. In the root region of the thread profile, the measured maximum hardness value exceeded 200 HV0.2, while at the crest of the thread, a maximum of 169 HV0.2 was recorded. This phenomenon can be attributed to thermal influence, specifically, greater material overheating in the root region of the thread profile compared to the crest, resulting in significantly higher hardness.

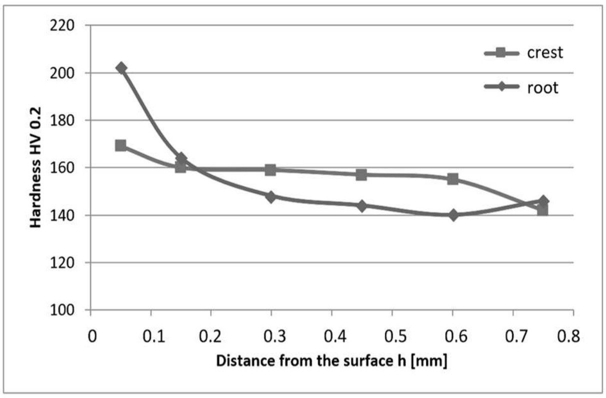


Fig. 15 *Comparison of the hardening progression at the root and crest of the thread using extrusion technology.*

4 Comparison of Results and Discussion

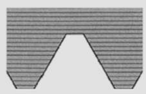
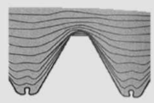
4.1 Design and Feasibility of Thread Production by Forming

For thread production by forming, the DIN 13-1 standard is not employed; instead, DIN 13-50 is used. Notably, the permissible deviations outlined in DIN 13-15 exhibit substantial differences compared to those in DIN 13-1. During thread forming, the fiber direction is altered, resulting in distinct permissible deviations.

4.2 Difference between Cutting and Forming of Internal Threads

Table 2 compares and distinguishes between the thread production technologies of cutting and forming. Following the recommended pre-drilled diameter has a small inner thread diameter, which falls within the permissible deviation range for the small inner thread diameter as defined by the DIN 13-50 standard. This presupposes the material-forming process.

Tab. 2 *Comparison and differences in thread production technologies: cutting vs. forming*

Procedure	Thread Cutting	Thread Forming
Fiber direction		
Properties	• Cutting of material fibers • Problems may arise with the thread profile angle	• Continuous fiber direction • Material cold hardening • Undeformed small thread diameter
Conseque n-ces	• Reduction of the yield load • Unfavourable stress distribution • Reduction of the load-bearing portion	• Higher resistance

4.3 The Impact of Pre-Drilling Diameter on Small Inner Thread Diameter

In the process of forming threads, specific pre-drilled diameters are required. These diameters depend on the malleability of the material being processed, tool geometry, and the intended thread engagement depth. Table 2 offers a comprehensive compilation of recommended pre-drilled diameters. When possible, opting for the maximum achievable diameter is advisable, as it prolongs the lifespan of the tool and reduces cutting forces. Even with a thread engagement depth of 50%, the continuous fiber orientation ensures adequate thread load-bearing capacity. This consideration acknowledges the influence of the pre-drilled diameter on the resultant small inner thread diameter.

4.4 Comparing the Progression of Hardening at the Crest of Thread Profile

Comparing the hardening progression within the crest region of the thread profile created through three distinct technologies, as illustrated in Figure 16, reveals the hardening progressions of each technology. As established in previous subsections, the crest region of the thread exhibits lesser hardening compared to the root region of the thread. The maximum HV0.2 hardness value was achieved during forming, specifically measuring 184 HV0.2, followed by extrusion with a recorded value of 169 HV0.2. The lowest hardness was recorded during cutting, measuring 160 HV0.2. These observed values distinctly underscore that the greatest hardness in the crest region of the thread profile was attained during forming, whereas the lowest occurred during cutting. An important aspect is that the process of thread forming induces an intensive plastic flow within the surface layer, resulting in deeper deformation compared to other methods.

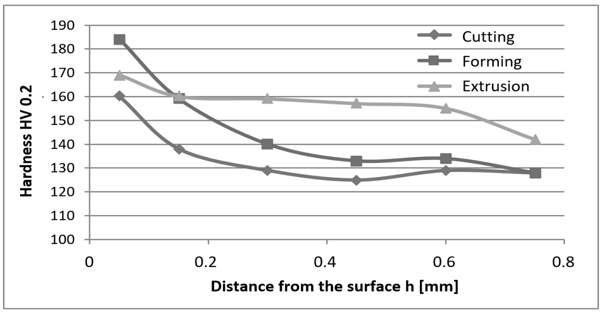


Fig. 16 *Comparison of the hardening progression at the crest of the thread profile*

4.5 Comparing the Progression of Hardening at the Root of Thread Profile

The final comparison involves the analysis of the hardening progression at the thread root, produced using three distinct technologies, as illustrated in Figure 17. In the thread root region, higher values of hardness were achieved in contrast to the crest of the thread. The maximum HV 0.2 hardness value of 211 HV0.2 was attained during the forming process, followed by extrusion with a recorded value of 202 HV0.2. The microhardness value within the thread root region during forming was higher than that achieved through the extrusion technique, although the difference in values is not significant. The reason for the higher hardness achieved at the thread root during forming is due to the fact that the deformation hardening was higher than thermal hardening – a phenomenon known as local overhardening. The lowest hardness was observed during cutting with the value of 155 HV0.2.

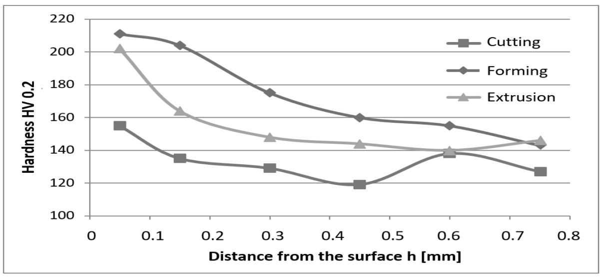


Fig. 17 *Comparison of the hardening progression at the root of the thread profile*

5 Conclusion

Machining technology is in a constant state of advancement and progress with each passing year. This continuous evolution is fuelled by the widespread availability of cutting-edge tools and techniques, consistently providing us with opportunities to enhance production efficiency and reduce economic costs. However, when we delve into the realm of utilizing various thread production technologies, a complex interplay of advantages and disadvantages emerges, intricately linked to their practical implementation within manufacturers.

The fundamental aim of our experimental verifications was to produce threads using three distinct technologies, followed by an in-depth analysis of the thread production process through comprehensive measurements of both hardening and thread microstructure. The thread production procedure encompassed a careful selection of appropriate materials and tools meticulously tailored for precise machining purposes.

The results from our experimental verifications have unveiled a multitude of intriguing findings, each of which holds significant implications for selecting the most appropriate thread production technology. Among the assortment of methods investigated, the cutting technology displayed the least hardening, measuring 160 HV0.2. However, this advantage is counterbalanced by the disruption of material fibers. Remarkably, this technology retains its prominence and popularity due to its potential for process automation and the wide availability of cutting thread taps in the market.

When comparing the hardening profiles of threads produced through forming and extrusion, only marginal discrepancies emerged. This prompted us to focus our efforts on identifying the key factor that could distinctly underscore the differences between these two technologies. Broadly speaking, the employment of extrusion technology, known as the Flow Drill process, results in a more extensive thread surface area, proving especially beneficial for thin-walled components. However, it is important to consider the substantial material hardening that could harm the lifespan of the tool. The key contrast lies in the fact that the extrusion technology exhibits limited compatibility with process automation, particularly in applications like CNC machining, leading to higher production complexity.

Acknowledgement

The article was created as part of the support of the grant project KEGA 015ŽU-4/2023 "Modernization of teaching chip technologies with elements of information technology based on networked virtual laboratories".

References

[1] BRANDÃO, G.L., CARMO SILVA, P.M., FREITAS, S.A., PEREIRA, R.B.D., LAURO, C.H., BRANDÃO, L.C. (2020) State of the art on internal thread manufacturing: a review. *The International Journal of Advanced Manufacturing*

Technology, 110:3445–3465; https://doi.org/10.1007/s00170-020-06107-x

[2] HEILER, R. (2018) Cold thread Forming – the chipless alternative for high resistant internal threads. *MATEC Web of Conferences*, 251, 02046

[3] CHAKHARI, J., DAIDIÉ, A.; CHAIB, Z.; GUILLOT, J. (2008) Numerical model for two-bolted joints subjected to compressive loading. *Finite Elem. Anal. Des.*, 44, 162–173.

[4] FRYDRÝŠEK, K.; ŠÍR, M.; PLEVA, L.; SZELIGA, J.; STRÁNSKÝ, J.; ČEPICA, D.; KRATOCHVÍL, J.; KOUTECKÝ, J.; MADEJA, R.; DEDKOVÁ, K.P.; ET AL. (2022) Stochastic Strength Analyses of Screws for Femoral Neck Fractures. *Appl. Sci.* 12, 1015. https://doi.org/10.3390/app12031015

[5] CORIA, I. ABASOLO, M., AGUIRREBEITIA, J., HERAS, I. (2020) Study of bolt load scatter due to tightening sequence, *Int. J. Press Vessels Pip* 182, 104054

[6] BHATTACHARYA, A., SEN, A., DAS, S. (2010) An investigation on the anti-loosening characteristics of threaded fasteners under vibratory conditions. *Mech. Mach. Theory* 45, 1215–1225,

[7] CORIA, I. MARTÍN, A.H. BOUZID, I. HERAS, M. ABASOLO (2018) Efficient assembly of bolted joints under external loads using numerical FEM. *Int. J. Mech. Sci.* 142–143, 575–582

[8] PANJA, B., DAS, S. (2017) Development of an anti-loosening fastener and comparing its performance with different other threaded fasteners, *Sa¯dhana¯* Vol. 42, No. 10, pp. 1793–1801_Indian Academy of Sciences DOI 10.1007/s12046-017-0719-4

[9] STRIZHAK, V., PENKOV, I. (2000) International Symposium on History of Machines and Mechanisms Proceedings HMM 2000 Distribution of axial load on bolt and nut threads, *Springer-Science+Business Media*

[10] CROCCOLOA, D., AGOSTINISA, M., FINIA, S., OLMIA, G., VINCENZIB, F.R.N. (2019) Steel screws on aluminium nuts: Different engagement ratio tapped threads compared to threaded inserts with a proper tolerance choice. *Tribology International* 138, 297–306. https://doi.org/10.1016/j.triboint.2019.06.001

[11] ANNA, C.A., GUILLAUME, F., GÉRARD, P. (2013) Analytical and Experimental Investigations on Thread Milling Forces in Titanium Alloy. *Int. J. Mach. Tools Manuf.*, 67, 28–34.

[12] REJZEK, M., JERSÁK, J., VOTOČEK, J. (2016) The Influence of Process Fluids on the Machining Process and Forming Internal Threads. In. *Manufacturing Technology*, 16(4):793-799, DOI: 10.21062/ujep/x.2016/a/1213-2489/MT/16/4/793

[13] JIANLI, S., ZHIQI, L., YONGTANG, L., (2017), Cold Rolling Precision Forming of Shaft Parts. Theory and technologies, *Springer-Verlag, Berlin Heidelberg*. http://dx.doi.org/10.1007/978-3-662-54048-0.

[14] TALU, Ş., (2019) Thread Rolling Technology. Napoca Star Publishing House, *Cluj- Napoca, Romania*. ISBN 978-606-690-890-0.

[15] TALU, S., SAGLAMB, H., KUSB, R., BRAMOWICZC, M., KULESZAD, S. (2020) Experimental investigations of threads surface integrity manufactured by cutting insert and with internal thread rolling head. *CIRP Journal of Manufacturing Science and Technology* 31, 334–341. https://doi.org/10.1016/j.cirpj.2020.06.007

[16] ELSHENNAWY, A.K., WEHEBA, G.S., (2015) Manufacturing Processes & Materials. *5th ed. Society of Manufacturing Engineers, Dearborn*, Michigan, USA.

[17] PATER, Z., GONTARZ, A., WERONSKI, W., (2004), New Method of Thread Rolling. *Journal of Material Processing Technology*, 153-154/1–3: 722–728.

[18] Heiler, R. (2019) Flow drilling technology and thread forming - an economical and secure connection in hollow sections and thin-walled components. *E3S Web of Conferences* 97, 06033, (FORM-2019), https://doi.org/10.1051/e3sconf/20199706033

[19] MIAO, H., SHAN, X., ZHANG, S., JIN, Y., ZUO, D. (2018) Process Online Monitoring on Cold Extrusion of Internal Thread in High-strength Steel. In. *Manufacturing Technology*, 18(6), 954 - 961 DOI: 10.21062/ujep/207.2018/a/1213-2489/MT/18/6/954

[20] HAMRAN, M. (2015) Odolnosť vybraných konštrukčných materiálov voči únave. Bachelor thesis. Žilina: UNIZA, 2015. 43 s

[21] Walter GPS. (2022) [online] <http://gps.walter-tools.com/touchtime/walter/#/home

[22] Garant Tool Scout. (2022) [online]. <http://www.toolscout.de/ToolScout/>