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CHANGES IN THE PROPERTIES OF THE SURFACE LAYER OF THE INTERNAL THREAD MADE BY COLD FORMING

ZMIANY WŁAŚCIWOŚCI WARSTWY WIERZCHNIEJ GWINTU WEWNĘTRZNEGO WYKONYWANEGO METODĄ WYGNIATANIA NA ZIMNO

Słowa kluczowe:

wygniatanie gwintów, mikrotwardość, własności warstwy wierzchniej

Key words:

tap embossing, microhardness, the properties of the surface layer

Abstract

The study presents the influence of cold forming internal threads on the property changes of the surface layer of the obtained thread outline. As a result

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of material deformation, hardening increases, which increases the strength of the thread. In order to determine such changes, the distribution of microhardness was measured around the outline of the thread. The measurements and metallographic investigations permit the conclusion that such threading increases the microhardness of threads, especially on the sides of the outline, and its growth depends on the diameter of the initial hole. Microhardness testing helped to identify the changes in the area of unfilled apex of the thread. Metallographic images enable observation of the deformation zone and the fragmentation and orientation of the structure during the formation of the internal thread. The paper also presents the results of the fem simulation of thread cold forming process.

INTRODUCTION

In modern technological processes, in addition to the conditions essential for granting the desired shape and dimensions in detail should, there should occur an increase in the mechanical properties of manufactured pieces. This leads to increased service life and the reliability of machinery and equipment and should result in lower costs of production. One from the many methods that meets the above requirements is the cold working process, into which belongs the technology of internal thread cold forming **[L. 1]**. While the rolling of external threads is widely used and technologically mastered, internal thread cold forming is still not very prevalent in the industry. The threads made by cutting taps quite often have errors in shape and dimensions, and it shows technological difficulties when machining hard materials **[L. 1, 2]**. In these and other cases, it is possible to replace the technology of the realization internal threads from cutting to cold working by the use of embossing taps, which can be roughly compared with the working of screwing self-tapping screws. In order to reduce friction during tapping, the forming tool has in its cross-section an outline similar to a polygon with rounded corners called ridges. The operating part consists of the embossing part, having the shape of a cone or in the latest designs – of curvilinear generatrix. This part of the tool performs the main job of shaping the thread. The calibrating part is slightly tapered towards the shank and determines the dimensional characteristic and shape of the thread **(Fig. 1)**. As a result of the interaction between the ridge tops of the tap and material, the deformed material moves between the sides of the threads of the tap filling the empty spaces **[L. 1–3]**. Almost all the material flows in the radial direction, filling the spaces between the sides of the thread tap. Depending on the diameter of the initial hole, it is possible to obtain a full or partial thread contour embossed on its tip. An incomplete outline of thread apex is approved by an amendment to the PN-84 / M-82054/01 developed in the research team of the Institute of Technology and Production Automation at Częstochowa University of Technology and published in the Bulletin PKNMiJ No. 5 May 1991, 33.

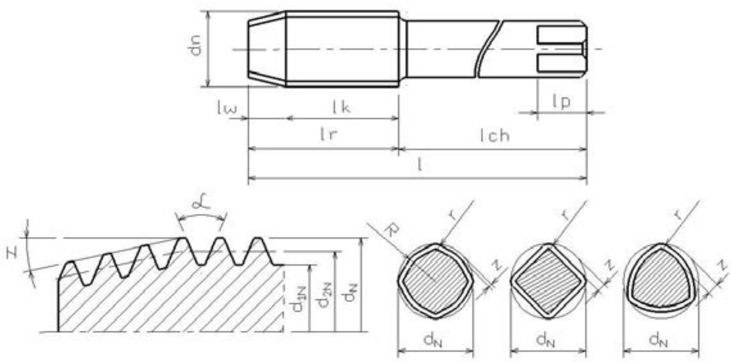

Fig. 1. Construction of the embossing tap (Sz - size rounding, R – radius of the inner circle, r – radius of the ridge, the other markings in accordance with standards for cutting taps) [L. 3]

Rys. 1. Konstrukcja gwintownika wygniatającego (*Sz* – wielkość zatoczenia, *R* – promień okręgu wewnętrznego, *r* – promień grani, pozostałe oznaczenia zgodne z normami dla gwintowników skrawających) **[L. 3]**

During tapping, individual ridges are shaping the thread profile. At any given moment, the thread is formed only on a specific operating part of the tap by apexes (ridges) in the way that the embossing allowance has been moved and thus the thread furrow is shaped, which is shown on **Fig. 2**.

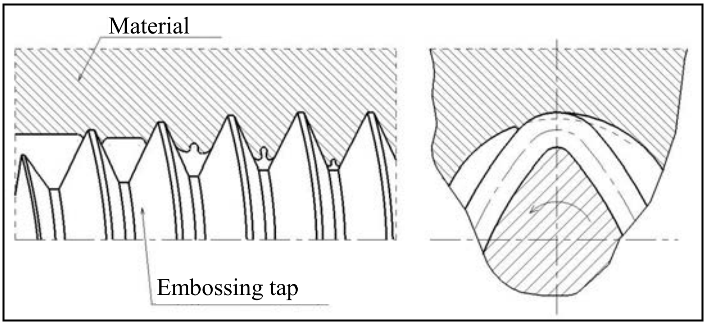

Fig. 2. Subsequent phases of the flank embossing [L. 3]

Rys. 2. Kolejne fazy kształtowania zarysu gwintu wygniataniem **[L. 3]**

Internal thread tapping by plastic cold forming has a big influence on the physico-mechanical properties of the macro and microstructure of the workpiece and on changes of its hardness. Research on the distribution of microhardness helped to determine the qualitative and quantitative changes in the surface layer of the thread. The increase in hardness results in an increase of thread shear strength of about 30%, and sometimes more **[L. 1, 2]**. Change of technology of the thread making from cutting to embossing in addition to increasing the strength and quality of the thread also results in an increase in the lifetime of taps from a few even to dozens of times in some cases. **[L. 1, 2]**. Metallographic and distribution of microhardness researches allows one to observe the effect of the plastic deformation of the nut material and the growth of microhardness that affects the increase in the contact strength of such thread.

RESEARCH OF SURFACE LAYER OF EMBOSSED THREAD

For experimental studies, M16 nuts were selected, made of steel 1.0050. This material is often used for the production of typical elements included in the threaded connections. The tool used was a 4-lobes embossing tap M16, as shown on **Fig. 1**. The embossing process was carried out on a lathe equipped with suitable tooling. Canola oil was used as the liquid-cooling lubricant. Microhardness measurements were carried out on properly prepared metallographic specimens. From the threads previously made, test samples were cut and put in frames with resin to facilitate their preparation and to simultaneously ensure correct mounting in measuring instruments **(Fig. 3)**.

Fig. 3. View of the prepared microhardness test samples
Rys. 3. Widok przygotowanych próbek do badań mikrotwardości

Tests were performed on samples with a smooth and polished surface with the oxide layer and dirt removed and after degreasing and etching.

Metallographic analysis

The deformation and stress state in the material causes the orientation of grains in the direction of maximum strain. Grains lose much of their original shape and become long and stretched. The boundaries between grains disappear and the material takes a fibrous structure. A sample of the metallographic view of thread cross-section is shown in **Figure 4**, where it is possible to observe and distinguish the following zones:

- A zone of clearly elongated grains oriented along the thread outline. The depth of this zone at the tip depends on the type of contour (complete or incomplete), and varies from 0.05–0.25 mm, and in the furrow up to 0.35 mm;
- A zone of the crushed grains located at a distance of approx. 0.1 to 0.3 mm from the surface of the thread at the top and from 0.35 to 0.65 mm from the bottom surface of the furrow;
- A transition zone characterized by a smooth change of the properties of the material deformed to a core state. Indication of the depth of this zone is possible only by means of microhardness measurement; and,
- A non-fulfilment zone (incomplete thread) is characterized by fine-grained structure with a slight orientation resulting from the complexity of the kinematics of flow in that part of the deformed material **(Fig. 4c)**.

The creation of the privileged structure orientation during embossing tapping has a direct impact on the improvement of physical and mechanical properties, in particular, the hardness and strength of the tapped material, and it does not depend on whether the deformation is caused by permanent compressive or tensile deformation.

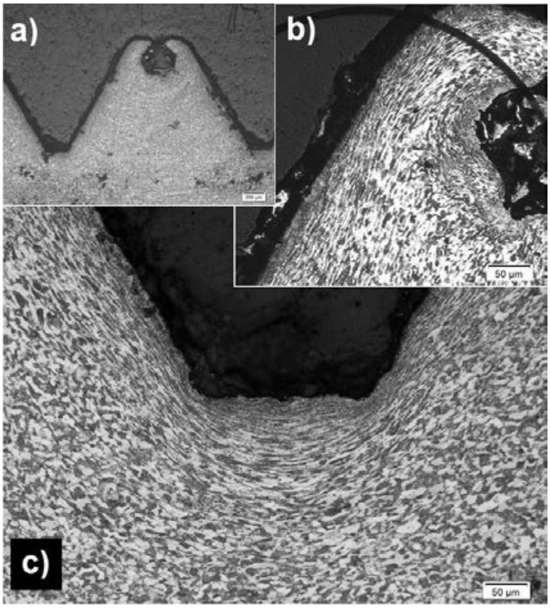

Fig. 4. Metallographic photo of thread cross-section M16: (a, b), view of the top of non-fulfilment of the thread outline, and (c) the bottom of the furrow

Rys. 4. Zdjęcie metalograficzne przekroju gwintu M16: (a, b) widok wierzchołka z niewypełnieniem, (c) dno bruzdy

Microhardness distribution

In order to determine the intensity of the movement of the particles of the material and the quantitative and qualitative changes of the embossing thread, microhardness tests were performed. Due to the low depth of the indentation, when measuring microhardness using Vickers test, retained special care was exercised when preparing the surface of the samples, which allowed minimizing possible measurement errors. A characteristic for the microhardness measurements is the use of small loading forces, which increases the dispersion of measurement results. Hence, the essential measurements are preceded by a statistical analysis, which determines the number of measurements and retries. This is particularly noticeable at low loads, because the primary reason for increased dispersion of results is the measurement error of the indentation diagonal. Microhardness tests were performed at 22°C using a microhardness tester VMHT UHL-002VD **(Fig. 5)** with fully computerized measurements and reading systems.

Fig. 5. Modern workstation for hardness measurement
Rys. 5. Nowoczesne, skomputeryzowane stanowisko do pomiaru twardości

The workstation provided surface perpendicularity of the specimen to the axis of the indenter. The time from the beginning of the application of force to achieve a nominal value was 10 s, with the speed of 30 μm/sec. With the load of 100gf, several test measurements were conducted from which the average value of the diagonal on the trace made by penetrator is d = 28.61µm, and the average microhardness is equal to 223 HV. On this basis, the following relationships were determined:

- The minimum measurement step from the indentation
- to indentation (4d): 114.44 µm;
- the minimum distance from the edge sample
- to the indentation (2,5d): 71.52 µm; and,
- The minimum thickness of the specimen (1.5d): 42.91 µm.

Figures 6 and **7** show the results of the measurement of microhardness and its distribution on the thread M16 made of structural steel 1.0050 As is apparent from the obtained values, the greatest microhardness strengthening of the thread occurred at the side surfaces, of about approximately 30%. When analysing the distribution of microhardness, it was found that, within the non-fulfilment of the thread, there are the smallest plastic deformations, and thus the lowest increase in hardening **(Fig. 6)**. The results also allow us to conclude that in this zone is not observed to have a drop in hardness, which might indicate a loss of consistency of the material. If the hole diameter is minimal, material completely fills the furrow, then the bottom of tap seals the peak, which is characterized by a high level of hardenings.

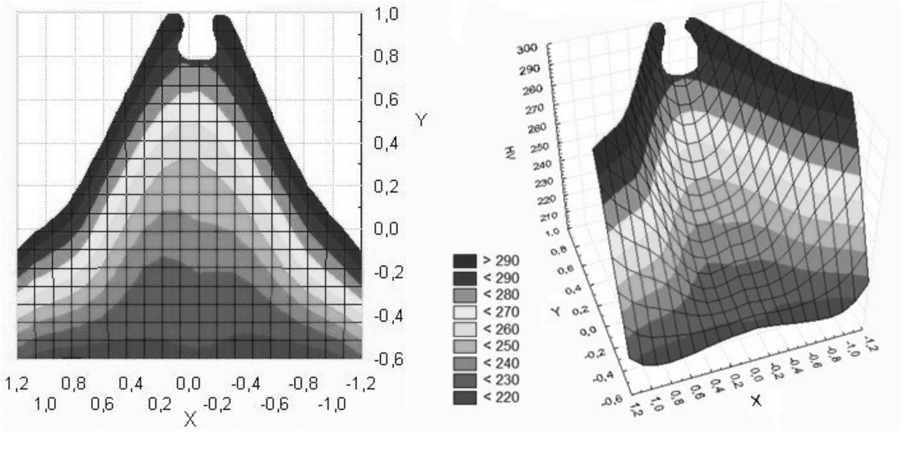

Fig. 6. Distribution of microhardness of the non-fulfilment thread profile
Rys. 6. Rozkład mikrotwardości gwintu o zarysie niepełnym

On the sidewalls, the rate of deformation (through compression) is higher than in the incomplete thread by an average of 40%, and in the central portion it is higher by approx. 30% **(Fig. 7)**. Due to the effects of the strengthening, such a situation it is favourable; however, in industrial practice, a tightening of the tolerance of the initial hole is required. Thus, its allowed to leave the apex not filled, which as shown on microhardness distribution graphs, because it has no negative effect on the strength of the thread. This allows one to increase the tolerance of the hole and has a direct impact on the growth of the lifetime of the tap, which is important in industrial conditions. There was also a small asymmetry in the distribution of microhardness on each side of the embossed thread. This is presumably formed due to deformations levelling the difference of the pitch on the embossing part of the tap relative to the sizing part.

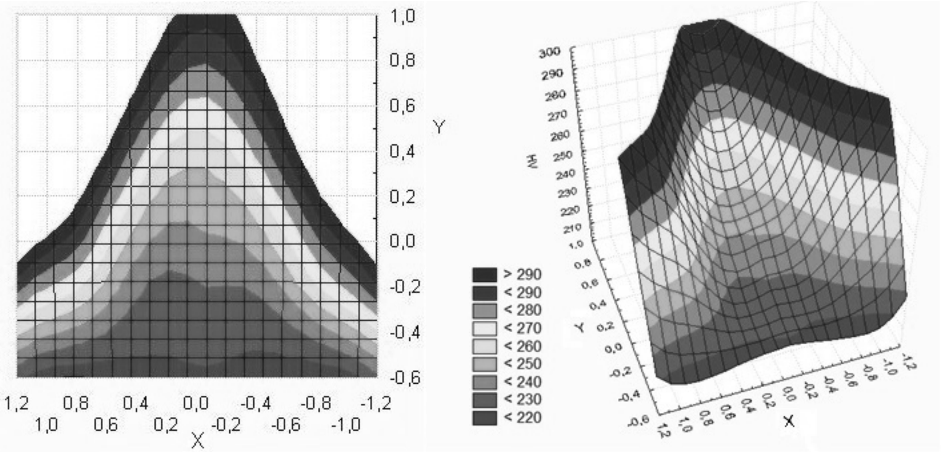

Fig. 7. Distribution of microhardness of the full thread profile
Rys. 7. Rozkład mikrotwardości gwintu o zarysie pełnym

SIMULATION OF THREAD EMBOSSING

This part of the paper presents the fem analysis of the embossing tapping. This analysis allows one to visualize the flow and strengthen of the material and observations of the elastic-plastic stress state, the forces and moments occurring during the embossing tapping. Furthermore, this analysis also allows one to determine the effect of the shape of the ridges on the loads occurring during thread embossing. To carry out the simulation, an Abaqus solver was used and a model of the tap was made in the Catia V5 software **[L. 3]** from which were determined three apexes. This procedure was necessary because the analysis for all of the tap would be very time consuming and difficult to perform. Next, a simplified model was imported into the Abaqus, where, by using the right tools, a finite element mesh, made the appropriate boundary conditions and torque was applied. The results of the simulation are shown in **Fig. 8**.

It is possible to observe the movement of the tap ridge and its impact on the workpiece. The results of the experiment essentially reflect the actual conditions occurring during the process of thread cold forming. Based on the

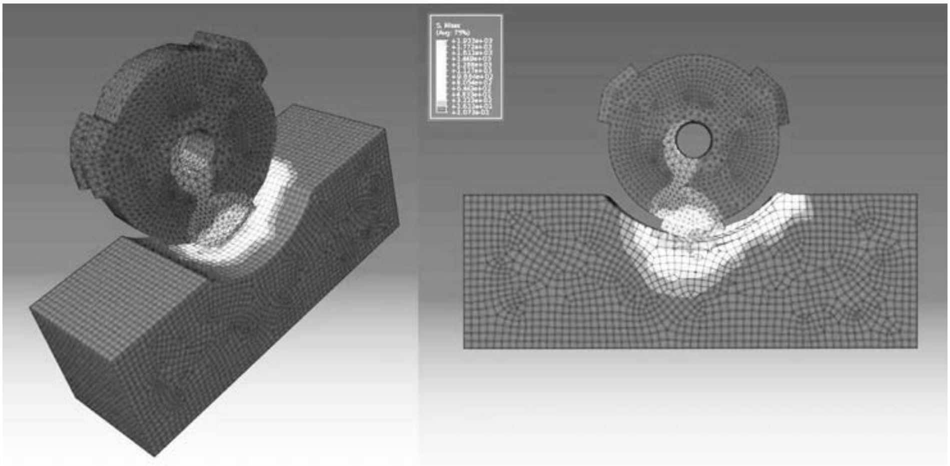

Fig. 8. View of the stress state and material flow during the thread embossing simulation carried out in the ABAQUS

Rys. 8. Widok stanu naprężeń oraz płynięcia materiału podczas symulacji wygniatania gwintu przeprowadzonej w programie ABAQUS

obtained data, it was found that the greatest stresses occur in the deformation zone of the material and on the ridge at the contact point between the tool and material. Deformation of finite element mesh illustrates a similar arrangement as in the metallographic pictures. Therefore, it can be concluded that computer simulation can accelerate the research of the embossed tapping process concerning the essence of the process of thread shaping and the design solutions of the taps. It may facilitate an analysis of the application of this tapping method to specific technical conditions and thereby shorten the time of research and experimentation.

SUMMARY

The surface layer of the thread is characterized by alternating properties relative to the initial material of the nut. Analyses of images demonstrate the positive impact of the thread embossing process on its metallographic structure. The layout and orientation of the microstructure changes indicate a material flow squeezed by the tap ridge in a general along curve of the outline. Thread microhardness measurements allows one to conclude that the embossed tapping increases microhardness (HV), particularly at the sides of the outline, and its growth depends on the diameter of the initial hole. Furthermore, there is a slight difference on the sides, which is probably due to a pitch error on the embossing part of the tap. Computer simulation and analysis of the obtained results may explain some of the phenomena occurring during the process of embossed tapping that have a direct impact on the physical and mechanical properties of the resulting thread outline and provide data helpful in assisting the selection of the appropriate shape of the tap.

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Streszczenie

W opracowaniu przedstawiono wpływ wygniatania gwintów wewnętrznych na zimno na zmiany właściwości warstwy wierzchniej uzyskanego zarysu. Na skutek zgniotu następuje wzrost utwardzenia, a tym samym wzrost wytrzymałości wykonanego gwintu. W celu określenia tych zmian dokonano pomiaru rozkładu mikrotwardości na całym zarysie gwintu. Przeprowadzone pomiary oraz badania metalograficzne pozwalają stwierdzić, że wygniatanie gwintów powoduje wzrost mikrotwardości, szczególnie na bokach zarysu, a jego przyrost uzależniony jest od średnicy otworu wyjściowego. Badania mikrotwardości pozwoliły określić zmiany w obszarze niewypełnienia wierzchołka gwintu. Zdjęcia metalograficzne umożliwiły obserwację strefy odkształcenia oraz rozdrobnienia i ukierunkowania struktury podczas kształtowania gwintu wewnętrznego metodą wygniatania. Zaprezentowano również wyniki badań symulacyjnych procesu wygniatania z wykorzystaniem technik komputerowych.