Performance of Internal Thread Rolling Head and The Mechanical Properties of Rolled Thread

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***Abstract*—Thread rolling process is widely used in external thread manufacturing, while limited use in internal thread. In this paper the mechanical properties of thread formed by the internal thread rolling head developed was investigated and their advantages were introduced. Cold forming plastically and permanently displaces the component material instead of cutting away material. With this model accurately dimensioned threads and significantly improved surfaces have been obtained. Therefore, the factors for internal thread rolling head were determined and the rolling head was tested successfully. The thread samples made by cutting and rolling were subjected to tensile test and their results were compared. As a result, the tensile load capacity of the rolled thread is found higher than the thread made by cutting method.**

***Keywords*—Plastic deformation, Cold forming, Thread forming, Thread rolling head, Tensile testing**

I. Introduction

Screwed fastener components are the most widely used products in industry. It has been estimated that fasteners comprise at least 1% of sales price of any finished product in which they are installed [1]. The auto industry, which constitutes one of the largest fastener markets, typically consumes fastener between 2800-3100 in the assembly of an average family vehicle [2]. Thread forming is being employed increasingly by industry because of the higher productivity rates and the elimination of chips. But it is not known about the mechanics of thread forming processes. The ability to predict the forces and torque generated during thread forming will helpful in designing better taps and better rolling head in the selection of forming conditions and obtaining optimal results.

Thread rolling is a cold or chipless forming process where a fluteless tap or a rolling head including rollers, having the reverse form of the thread, displace raw material to produce internal threads in blank holes with no material losses. Internal threading is produced by an action similar to thread rolling by deformation of material than cutting. The advantages are not only excellent surface finish but also a good surface hardness and increase in thread strength up to 40%. All ductile materials can be thread rolled internally with a good impact value. The primary reasons preferring rolled threads are lower unit cost, good surface hardness of threads, no chip formation hence blind holes can be threaded easily, good grain flow structure, reduced material utilization, and superior mechanical properties. As a consequence, thread rolling has virtually eliminated thread cutting as a competitive technique for fastener produced in quantity [3]. By cold forming manufactured workpiece profiles are characterized by high accuracy, reliability and durability. Because of the rolling process, the formed threads and flanks allow an increased load to be applied in use [4]. Although several threads forming by cutting have been created and performed on CNC machines, thread with rolling is still lower production time and lower labour and production cost due to formed completely in one pass of tap or rolling head.

In cold forming, usually low-carbon steels are used. Thread rolling is primarily a cold forming process done at room temperature; it is possible to roll internal threads in both ferrous and non-ferrous metals provided that their hardness (as Brinell) and tensile strength are not above 200 and 800 MPa, respectively [5, 6], and it has an elongation of 10-40%. Areas of application include aluminum and its alloys, brass having copper %more than 62; and steel, stainless steel, free cutting steel. About 60 % of the materials used in industry nowadays can effectively be formed in this way. It is also established that there is an analytical relation between hardness and effective strain induced in a metal during cold working.

Most of the attempts to model the thread forming process to date have focused on external thread forming using dies [7, 8, 9]. Hayama [10], developed a model, using the minimum energy method and partially plastic deformed thick walled cylinder theory to predict the maximum torque values experienced during the internal thread forming process. Ivanov and Kirov [5, 6] developed an empirical formula for finding the maximum value of torque experienced in internal thread forming. The each tooth tap or rollers of thread head come into contact with the workpiece material deform the work material and deformed material flows upwards along the faces of the faces of the tooth or rollers. With the successive tooth or rollers forms the thread at desired depth of cut. During the rolling process the forces generated are both due to the deformation of workpiece and resulting flow of deformed material along the faces of the tooth [10]. Plastic deformation also creates work hardening of work material. Knowing that inducing plastic deformation alters material's strength, different regions of cold formed part will have different strengths. Generally, cold formed parts are forged in a number of stages and in each stage the material undergoes additional permanent deformation [11]. It has been considered that there is a close correlation between the hardness of a cold formed product and strain hardening because of cold forming. To compensate for the elastic deformation component in pressing of internal threads, correction must be introduced when calculating the mean diameter, internal diameter and external diameter of the taps.

In cold rotary forming, such as screw threads, it is well known that the fatigue strength of rolled products increases than that of blank material. While Kawai [12] reported that the profile forming ratio in groove rolling affects the fatigue strength of groove-rolled products, it has been considered that the fatigue strength of rolled products is dependent on the strain-hardening of material and the residual stress built up during the rolling process.

The replacement of sliding friction by rolling friction is an important utility for load reduction. This advantage is applied on thread rolling head which have rollers to deform blank materials. Despite their great design exemplars [13, 14, 15] thread rolling heads are not wide spread therefore, there is no more information in the literature.

The aim of the study is to design an adjustable internal thread rolling head and manufacture it to carry out rolling practice in order to show the performance of the rolling head by mechanical tests and also take an attention about the advantages of rolling internal threads.

II. INTERNAL THREAD ROLLING

Product designs that fully exploit the mechanical properties and compressive residual stresses of rolled threads have not been fully realized due to the current lack of predictive capability correlating thread properties to process parameters [16]. Thus, work to develop analytical models of process behaviour and scientifically based methodologies to optimize product properties for thread rolling is clearly needed. In order to develop a better understanding of how selected process parameters influence thread profile and metal flow during internal thread rolling, a parametric study must be performed on flow behaviour, thread profile and the relationship between process parameters. It is evident from the flow lines that the material along the root and flanks of each tooth is highly elongated and compressed. Near the peak and in the thread interior, the grains are also elongated but are oriented parallel to the direction of rolling head roller penetration as a result of being compressed by the flanks to fill the peak. An individual thread can be considered to be rolled by progression penetration of an indentor into blank surface. Based on results obtained from experimental trials, it was determined that the thread rolling process could be reasonably simplified to a 2D plane strain problem where metal flow was assumed to occur in the radial and longitudinal directions of the blank with negligible spread in the hoop or circumferential direction [17]. While the properties of the thread flank are a critical factor in determining fastener performance, it was felt that a comparison of the effective strain at the crest and root would provide a better measure of deformation resulting from the rolling operation.

Due to the widely usage of steel material in fastener production in industry, low carbon steel Ç1020 (equivalent to AISI1020) was selected for internal testing. Blank diameter, friction, thread geometry, and mechanical properties of the blank material are accepted to be important factors. The thread profile and the basic properties of an ISO metric thread is shown in Figure 1.

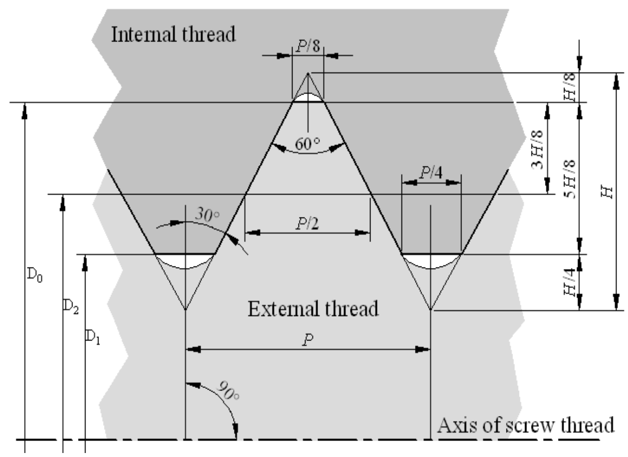
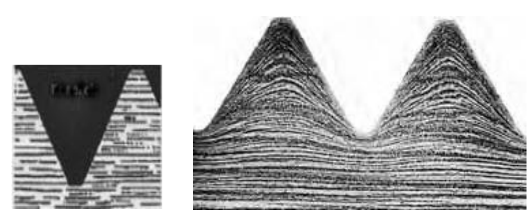


Figure 1: Screw thread nomenclature

The thread rolling process is economical because of the benefits of cold working. Rolling speeds are ranging from 20–90 m/min. These values are considerably higher than the cutting speeds used in thread cutting operations. When cutting with thread chasing heads speeds rarely exceed 10 m/min. In this process, the component material is stressed beyond its yield point, being deformed plastically and, thus permanently. When a thread is rolled, the fibers of the material are not severed as they are in the cut thread shown in Figure 2a. Rolled threads are reformed or forged in continuous unbroken lines that follow the contours of the threads, as shown in Figure 2b.



(a) (b)

Fig. 2 Comparison of a) cut thread and b) rolled thread

Rolled threads resist stripping because shear failures must take place across rather than with the grain. For the reason that threads are incrementally formed by progressive penetration of the rollers into the blank hole surface during a fixed number of blank/rolling head revolutions, internal thread rolling operations can be represented approximately as plane strain pressing of a workpiece using a parallel set of wedge-shaped indentors. It is evident from the flow lines that the material along the root and flanks of each tooth is highly elongated and compressed. Near the peak (crest) and in the thread interior, the grains are also elongated but are oriented parallel to the direction of die penetration [17] as a result of being compressed by the flanks to fill the crest. Lack of sub-surface deformation in the blank was confirmed by hardness testing of rolled blanks which showed that the base hardness of material below the threads was unchanged after rolling [18].

At the first stage, (penetration rate is 10%) each thread is essentially un-deformed and the flanks of each thread are seen to form separately from one another. Deformation is localized around the contact between the blank surface and tips of rollers (Figure 3a). At the second stage, (rate of penetration is approximately 20-35%) adjacent material at the free surface of an individual tooth is also displaced horizontally but tends to flows upwards along the tool flank, causing a small pile to create on both side of the each tread. With continued tool penetration (Figures 3b and 3c), the initial flow pattern is maintained along the circumference of each roller although additional blank material is now being deformed causing the size of the deformation zone to increase in size.

At the third stage, (when nearly 50% of thread is completed), the situation is characterized by the onset of deformation and flow in the interior of individual threads and filling of the thread peak. The displaced material from next thread flanks begin to coincide at the surface (Figure 3d). Since the horizontal flow (z-direction) is opposed to next threads, continued penetration by the roller causes lateral extrusion of each thread.

At the fourth stage, (Figure 3e, 90% rate of penetration), continued inward flow of material (r-direction) is restricted and further roller movement results in material being increasingly displaced towards the blank interior to fill in the peak. The full peaks (100% penetration) are hardly ever achieved in practice and rolling is usually stopped prior to complete roller penetration.

Friction is another important factor in thread rolling processes in that it influences the power required for rolling and a material's rollability. Losses from friction represent a significant amount of the total power consumed during rolling and can range between 10 and 30% of the total power consumed [19].

Mechanical properties, along with internal rolling head design and process conditions are known to have a strong influence on the thread profile developed during rolling and the tendency for a particular material to form seams. Harder materials and those having a high rate of work hardening are attributed to suppress the tendency towards seam formation in the thread crest [20].

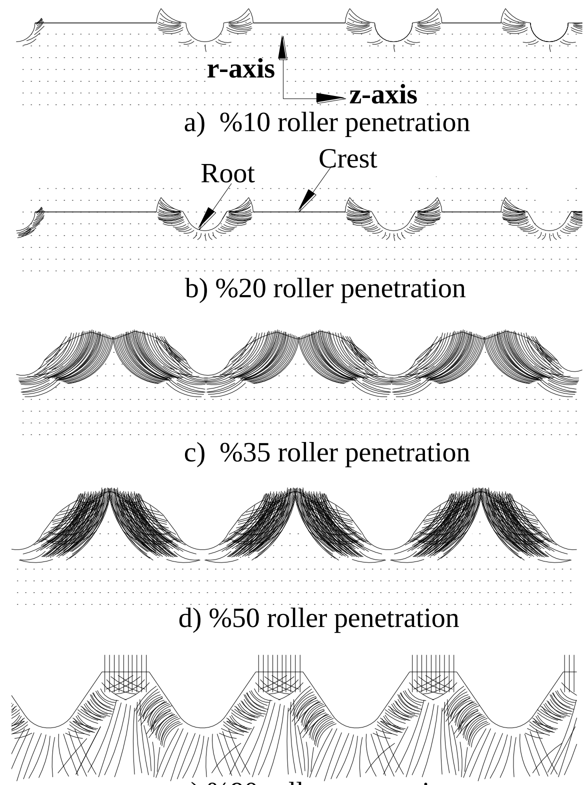


Figure: 3 Material flows during rolling effect

III. INTERNAL THREAD ROLLING HEAD

The adjustable rolling head developed for internal thread is shown in Figure 4, [21, 22]. This rolling head has been designed and manufactured for rolling of thread 80-86 mm in diameter and thread pitch of 1.5 mm. The rollers (04) are supported in needle rollers on the axles (05). In order to adjust the head to a defined size, firstly the fixing screws are loosed. The thread pitch diameter is obtained by rotating of cover (01) and together with profile support stems (08). The partial movement of support stems moves out the roller carriers (03) and rollers (04) as well. After the desired diameter is verified by measuring the fixing screws is tightened. The roller carriers are drawn constantly against the stem by clip a ring.

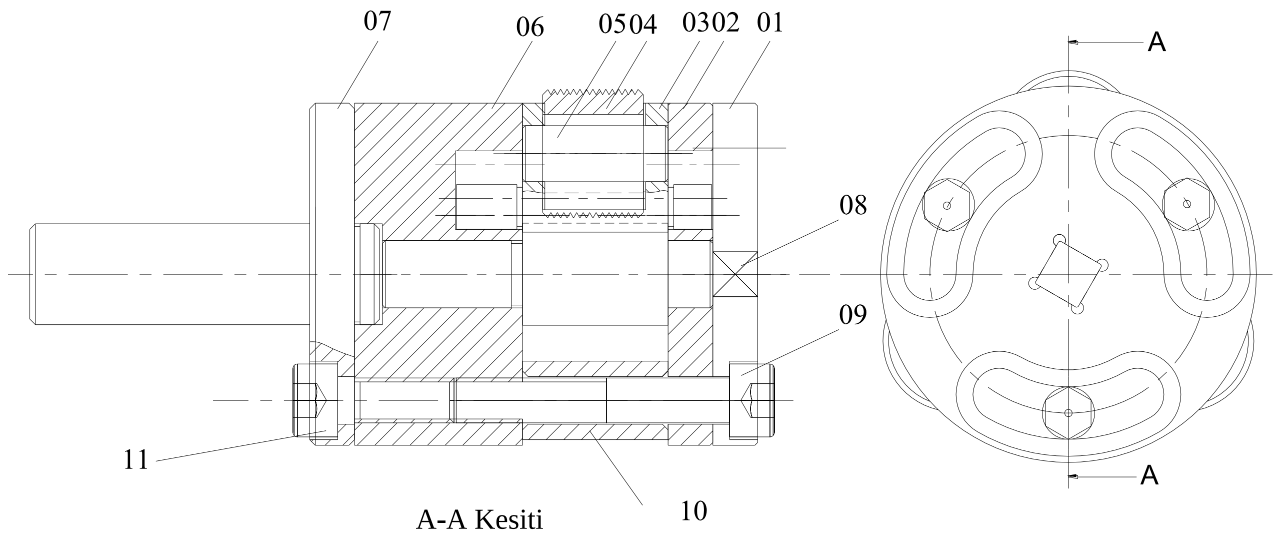


Figure 4: Adjustable internal thread rolling head

IV. THE MECHANICAL TEST APPLIED TO ROLLING THREAD

The pitch and blank diameter will be important parameters that affect material flow and pressure acting on the rolling roller. While the effect of initial blank diameter on roller life is well documented, relatively little has been written about the effect of the blank diameter itself for a given pitch and thread form. In triangle formed threads lower strain contours would be generated in the root while trapeze formed threads have strain contours due to the restricted material flow around the rollers. The burnished thread surface with a roughness level of below 5 μm improves resistance to corrosion and reduces abrasion within the thread. The work hardened flank provides increased surface tensile, yield, and shear strength. Due to pressure deformation, a residual compressive stress system builds up at the thread root, which counteracts tensile loading. Approximate drill size=major diameter-(0.45*pitch).

A. *Tapping, cutting and rolling experiment*

The thread rolling process is performed by internal thread rolling head carries out the primary rotary motion and the axial feed motion while the blank is fixed. After a particular rolling length is achieved the rotary motion is reversed and the rolling head withdraws from the blank hole. It is possible that the movements can be conducted by only the head or the head and the blank together, depending mechanism of machine tool.

It has been prepared two types of samples for tensile test of internal rolling: the samples rolled by rolled tap and cutting tap in size of M12x1.75 mm and the samples rolled by internal thread rolling head and made in lathe by thread insert in size of M80x1.5 mm. In order to compare the rolling thread with cut thread each group of samples were machined identically and were subjected to tensile testing at the same conditions. The two test specimen of engineering drawing is shown in (Fig. 5a).

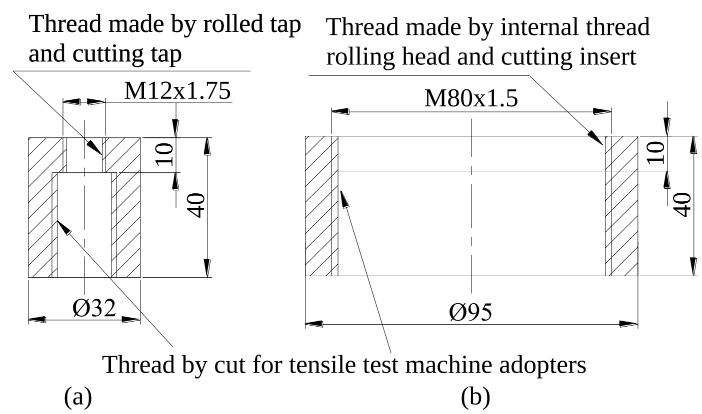


Figure 5: Test specimens for tensile testing

The blank samples of M12x1.75 (Metric ISO thread DIN 13) were pre drilled in internal thread minor diameter of 10.2 mm for cutting tap (for tolerance of 6H) while the diameter 11.2 mm for rolling taps. The thread engaging length for all tests was kept constant as 10 mm. The tapping processes were performed by means of automatic tap holder with adjustable torque at the same conditions on drilling machine (Retosan RM 35 ES) and following that the threads were checked with screw thread gauges. The thread of M18x2.5 formed the other side of the samples are used for thread drawing.

After the samples for M80x1.5 were machined at the same sizes as shown in Fig. 6b, the blank holes were machined in internal thread minor diameter of 78.05 mm and thread turning were carried out by thread cutting insert while the some blank holes were machined in diameter of 79.35 mm that should be given by:

$$d_p = D\text{-}0.2p\text{-}0{,}00403.p.f_1+0.0127.n \quad (1)$$

where f_1 is the percentage of thread engagement % f_1=90, n is RH limit number, p is thread pitch and D is internal thread major diameter. The rolling tests were also conducted on the drilling machine and the universal lathe as well.

The cutting speed were selected 16 m/min for tapping while rolling were carried out at rotational speed of 90 and 56 rpm for rolling tap and thread rolling head, respectively. The operation of tapping and rolling are shown in Fig. 6.

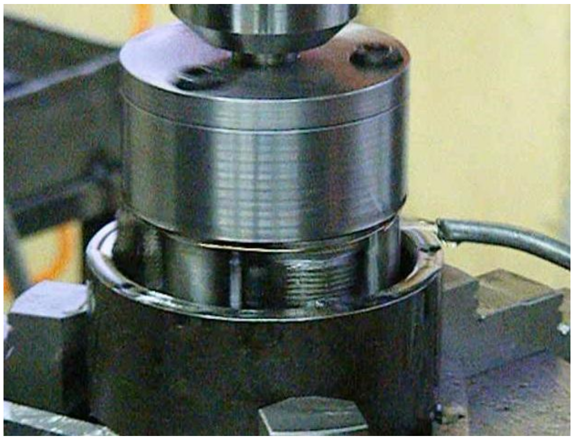


Figure 6: Tapping and rolling operation on drilling machine and lathe

A. Tensile testing

In order to define the mechanical properties of the samples they were applied to tensile testing. Before testing two adapters were screwed to both side of the test specimen and the mounted system was placed both jaws of the testing machine (Figure 7), then the specimen was started to extend until the tapped or rolled screw thread (in length of 10 mm) was deformed completely or the drawing adapter was drawn from the specimen. The threaded adapters were heat treated at 40 Rc to resist deforming and each of one was used for one experiment. Each test was repeated three times and the average values were considered for investigating. Meanwhile maximum tensile load and strain rate were recorded.

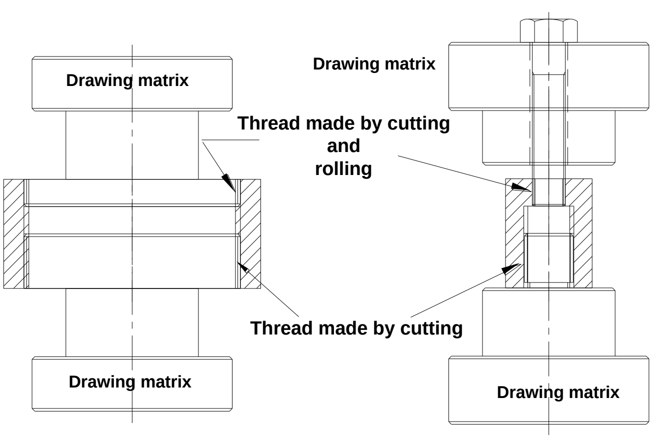


Figure 7: Preparation of the specimens for tensile testing

The achieved maximum tensile loads and the average of maximum tensile load values for M12x1.75 and M80x1.5 have given in Table 1 and Table 2, respectively. According to that the average maximum tensile load for thread made with cutting tap was 50.3 kN while this value is 65.53 kN for thread made with rolling tap. Thus the average maximum tensile loads of threads made with rolling tap has shown increase as 23% compared to threads made with cutting tap. In the same way, the average load for thread made with cutting insert was 205.45 kN while it is 247.13 kN for thread made with internal rolling head developed. In that case it is found that the average tensile load of the thread made by rolling head is higher than 17% compared to the thread made with cutting insert.

Table 1: Tensile test results of M12x1.75 for threads made with cutting and rolling tap

Thread made cutting tap		Thread made rolling tap	
Thread length (mm)	Maximum load (kN)	Thread length (mm)	Maximum load (kN)
10	42,5	10	67,3
10	56,9	10	65,6
10	57,6	10	61,8
10	44,1	10	67,4
Average	50,3	Average	65,525

Table 2: Tensile test results of M80x1.5 for threads made by cutting and internal rolling head

Thread made by cutting		Thread made by internal rolling head	
Thread length (mm)	Maximum load (kN)	Thread length (mm)	Maximum load (kN)
10	215,7	10	278,7
10	234,7	10	228,5
10	176	10	238,5
10	195,4	10	242,8
Average	205,45	Average	247,125

V. RESULT AND DISCUSSION

Since thread production with rolling method is being a plastic deformation, the displaced/deformed raw material with rolling roller is formed coincide with to matrix shape. In this study internal thread rolling process was carried out by internal thread rolling head developed and manufactured. Three number of roller made of HSS (M42) was used in order to reduce friction forces and to achieve a good surface quality during deformation. During rolling of roller on raw material, the material has not only taken thread form but also caused hardening of flank surface depends on cold deformation. The screw thread as a result of tensile force acting its flank surfaces is started to squeeze and the tensile force is increased till the maximum squeezing limit of first thread, following the destroying of first thread the other threads subjected to squeezing continuously while the tensile force is reduced.

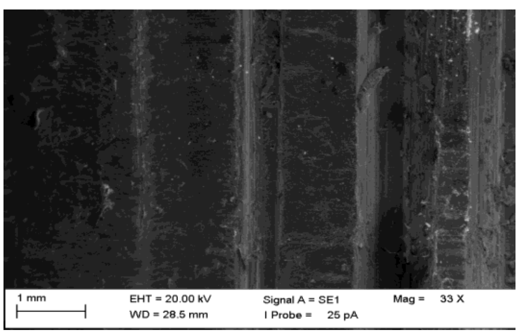
The damage formation till to be drawn of the thread can be expressed as end failure. It is shown that the tensile test graph, the section picture of the drawn thread, the SEM view, the view of the threads squeezed and directed towards to drawing direction on optical projector are in Fig. 8a-c, respectively for the thread of M12x1.75 made cutting tap. In order to oppose destroying of the matrix during tensile testing the bolt made of chrome-nickel was used for each experiment. It was observed that not only the samples threads are deformed but also drawing bolt and matrix as well. When SEM view of thread made with cutting tap is investigated it is seen tears and burrs on thread flanks depend on cutting, these increase the notching effect and cause to breaking off the thread in addition to drawing off. The threads especially in exit side are given image as if to be wiped out. The tensile strength of thread in Fig. 8 is 56.9 kN while 65.6 kN in Fig. 9.

In Figure 9 it is shown the tensile test graph, fractional section picture and SEM view of the drawn thread of M12x1.5 made by rolling tap. When the tensile test graph is investigated it is seen that the thread was initialized squeezing after the tensile force was reached to maximum instead of wiping out immediately towards to loading. The rolled treads have high tensile strength compared to thread made with cutting tap. It is observed that there is a routine squeezing but not tears on the screw threads in place of breaking off.

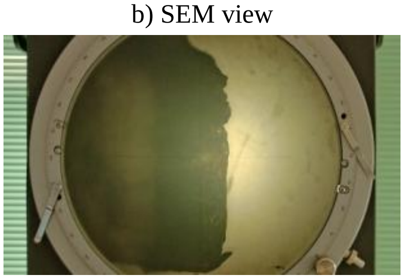
The graph and views for the thread of M80x1.5 are given in Figure 10 that exhibit same character as in Fig. 8 that represent the drawn thread made by cutting tap. Here the squeezing is seen mainly on thread crests, it has not been observed considerable destroying on thread roots and drawing matrix.

In Figure 11, the graph and the views about the thread of M80x1.5 made by internal thread rolling head developed were presented. The threads start to squeeze when the tensile load was reached to maximum tensile load. According to SEM views it was not observed any destroying on thread roots in spite of squeezing on thread crests; therefore, this situation has shown that the rolled internal thread has created high strength to breaking off under load. During tensile testing threaded end of the drawing matrixes was destroyed obviously in spite of heat treated at Rc 35 in order to being durable.

a) Section view of the thread



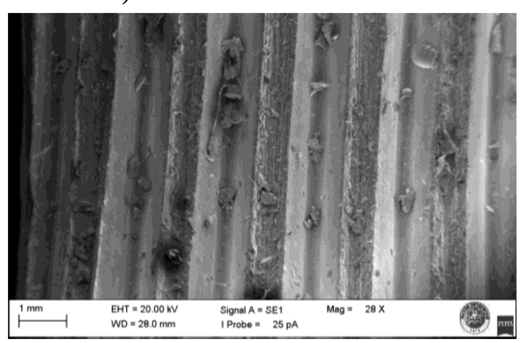
b) SEM view



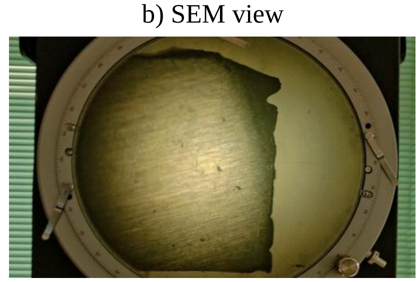
c) View of thread section on optical projector

Fig. 8 The view of thread M12X1,75 made by cutting tap

a) Section view of the thread



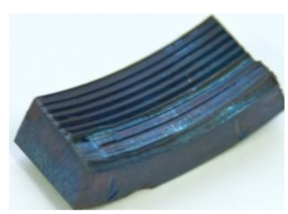
b) SEM view



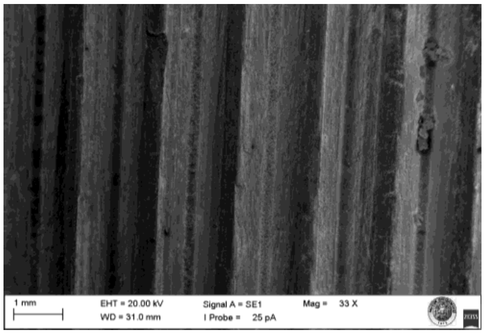
c) View of thread section on optical projector

Fig. 9 The view of thread M12X1,75 made by rolling tap

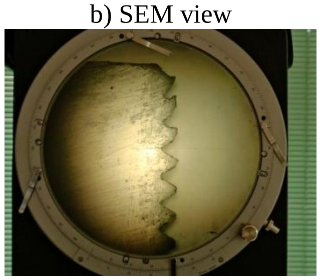
a) Section view of the thread



a) Section view of the thread

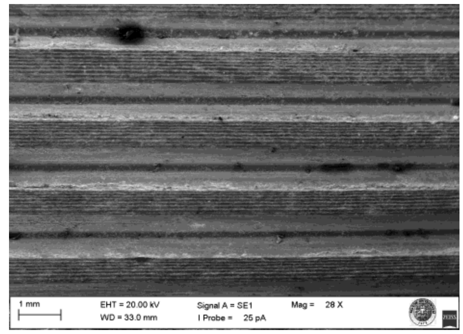


b) SEM view

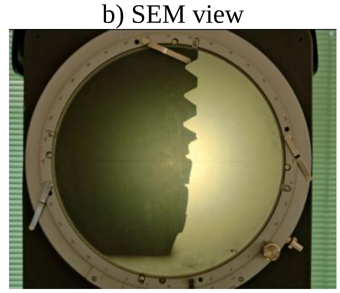


c) View of thread section on optical projector

Fig. 10:The view of thread M80X1,5 made by cutting insert at drawing load of 215,7 kN



b) SEM view



c) View of thread section on optical projector

Fig. 11: The view of thread M80X1,5 made by internal thread rolling at drawing load of 278,7 kN

VI. Conclusion

The design of the internal thread rolling head have been developed and tested on different materials such as aluminum and steel at elevated rpm in drilling machine and a universal lathe. The threads made by cutting and rolling were subjected to tensile test and when the test results are compared it is found that the tensile load of rolling tap is higher than cutting tap in 23 % in size of M12x1.75 while the thread made rolling head is higher than the thread made by cutting insert in 17 % in size of M80x1.5, respectively. While a thread on turning machine is completed with 13 passes by cutting insert, it is performed with one pass by rolling head. That is a 90% (or more) reduction in cycle time. A rolled thread is more precise and consistent than a cut thread, eliminating the need to closely monitor thread making production. By eliminating the need for constant size adjustments, set-up and down time costs are reduced, resulting in a significant cost savings.

Since the test applications has been lasted the other mechanical tests such as fatigue and torsion will be carried out later on. As a future research the adjustable design of thread rolling head can be transformed into closed design as compact by engaging with a control mechanism in order to remove the reversing of rotary motion. It is thought that he rolling time will be reduced while the tool life of rolling roller is increased. If the rolling head is adapted to CNC turning machines and machining centre it will be reached to expected aim.

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