Internal thread cutting process improvement based on cutting tools treatment by composite powders in a magnetic field

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Abstract

This article deals with the subject of using iron and titanium carbide (Fe + TiC) based composite powder for treatment of cutting tools in a magnetic field with the purpose of improving internal thread cutting process. As a result of studies performed by us, it has been established that composite powder grain size influences the condition of the contact surfaces of cutting tool teeth and process efficiency. Also a relationship has been discovered between the changes in internal thread roughness and the condition of thread tap teeth contact surfaces pretreated in a magnetic field by Fe + TiC composite powder having various grain sizes.

Keywords: internal thread, thread cutting, thread surface roughness, thread tap, magnetic-abrasive finishing, tooth contact surfaces condition, composite powder

Kulcsszavak: belső menet, menetfúrás, menet felületi érdessége, menetfúró, mágnese-abrazív felületkezelés, fog kontakt felület minősége, kompozit por

1. Introduction

Fatigue breakdown of thread joints operating under dynamic loads causes emergency and unscheduled machine shutdowns, resulting in increased equipment downtime and financial costs. Fatigue breakdown of thread joints is often encountered in practice; therefore, it forces production workers and researches to think over possible ways of solving this problem time and again.

Quite a wide range of design measures intended to increase fatigue resistance is proposed nowadays. Design assurance is a necessary measure; however, it is not sufficient. Technological measures that ensure necessary quality characteristics of mating thread surfaces also play a great role in fatigue strength improvement [4]. For example, Yakushev found out in his studies [15] that forming thread surface roughness with parameter $R_a = 0.63 - 1.25 \mu\text{m}$ increases fatigue strength of a thread joint several times as compared to a threaded joint with surfaces roughness parameter $R_a = 2.5 - 3.2 \mu\text{m}$.

At present, no significant complications arise as the exterior thread surface microrelief is formed. However, internal thread is quite a different story: it is rather difficult to ensure roughness parameter $R_a \leq 1.6 \mu\text{m}$ on its flanks. It is especially difficult with items made of corrosion resistant materials that are very often used in power engineering. In this regard, the studies performed by these authors are aimed at forming internal thread surfaces in workpieces corrosion resistant materials so that internal thread flanks roughness would be within $R_a = 0.63 - 1.25 \mu\text{m}$.

The most common process of forming a internal thread profile is the internal thread tapping process [3, 10, 12]. In spite of its popularity, it has significant drawbacks connected with ensuring the quality indicator specified above.

The technological reduction of internal thread surface roughness $R_a < 1.6 \mu\text{m}$ during tapping is inseparably associated to the improvement of the condition of cutting tool teeth contact surfaces that can be effected by performing finishing operations. Magnetic-abrasive finishing (MAF) [6, 7] is a promising method of forming various conditions (rounding radius, roughness and microhardness) of tooth contact surfaces of a thread tap.

Magnetic-abrasive finishing [1, 5, 13-14, 17] is essentially abrasive effect made of a workpiece (a thread tap) (Fig. 1) by ferromagnetic powder abrasive mass compacted by magnetic field [6-9, 11, 16]. Using MAF as final machining of thread taps allows to remove the previous defective layer and to form a new, hardened one, to round off the cutting edges to the necessary limits, as well as to reduce the roughness of cutting teeth contact surfaces in a relatively short space of time ($t = 60 - 210 \text{ s}$). As an example, it is presented in Fig. 2 photographs of contact surfaces of a thread tap teeth before and after magnetic-abrasive finishing [7].

A substantial change in the condition of thread tap teeth contact surfaces is caused by specific features of magnetic-abrasive finishing, namely oriented and selective abrasive microcutting and microsmoothing [7]. Magnetic-abrasive powder having a high cutting power and enhanced magnetic properties plays a major role in microcutting and microsmoothing. However, it is not possible to ensure them at the same time for grains of a homogeneous material. Therefore, the sphere of application of magnetic-abrasive powders made of homogeneous materials is limited to machining of soft materials. It is possible to attain high hardness and good magnetic properties by creating powder materials in which every grain is a composition from ferromagnetic base and hard non-magnetic inclusions.

Fig. 1. Magnetic-abrasive finishing of a thread tap: 1) – the tap; 2) – magnetic-abrasive powder; 3) – pole tips; 4) – solenoids.

1. ábra Menetfúró mágneses-abrazív felületkezelése: 1) fúrószerszám, 2) mágneses-abrazív por, 3) elektródavégek, 4) tekercsek

Fig. 2. Thread tap teeth before (the upper row) and after (the lower row) magnetic-abrasive finishing: a and b) the 4th tooth at the inlet section; c and d) the 6th tooth at the calibrating section

2. ábra Menetfog a mágneses-abrazív felületkezelés előtt (felső sor) és után (alsó sor): a és b) a negyedik fog a beömlési szelvényben, c és d) a hatodik fog a kalibrálási szelvényben

The most efficient composite magnetic-abrasive powder is a composite based on iron and titanium carbide (Fe + TiC) [1], a final product of chemical interaction resulting from combined heating of mixtures Fe + C + Ti. The presence of iron in the process of synthesis does not impede generation of titanium carbide in the temperature range from 1400 to 1600 °C. However, a rise in temperature brings about a reduction in titanium carbides content in the composition because of their dissolution [1].

Analysis of the Fe + TiC composite powder microstructure (Fig. 3.a) demonstrates that dark rounded spots (globules) of titanium carbides are observed against the light background of iron matrix. The globules differ in size insignificantly; they are distributed evenly throughout the matrix field. The size of the globules depends on the carbide phase concentration in the composition, i.e. grains grow larger as carbide concentration increases. The rounding of globules is caused by a limited capacity of titanium carbides dissolution in iron and the striving of every system to take the form that is the most suitable for it [1].

Powder particles are shaped as irregular polyhedrons (Fig. 3.c) with protruding carbide grains being abrasive cutting areas. The surface morphology of a high-melting abrasive in ferromagnetic matrix, its size and shape are presented in Fig. 3.b.

The microstructure of powder consists of carbides in the form of spherical, flakey and cast inclusions in iron matrix. The microhardness of ferromagnetic matrix is within the range of 2,100 – 3,400 MPa and that of Ti-C is 30,000 – 31,000 MPa. High microhardness of titanium carbide, a low level of its interaction with iron at high heating temperatures and, as a consequence, good magnetic properties of powder allow to ensure intense removal of base metal and an improved quality of the machined surface [1].

a)

b)

c)

Fig. 3. Composite magnetic-abrasive powder based on iron and titanium carbide (Fe + TiC): a) powder microstructure; b) particle morphology; c) the shape of grains [1]

3. ábra Vas és titánkarbid (Fe + TiC) alapú kompozit mágneses-abrazív por: a) por mikroszerkezet, b) szemcse morfológia, c) szemcsealak [1]

Thus, the purpose of the studies carried out by these authors is to improve the internal thread tapping technology through preliminary treatment of the thread tap using the MAF method with the help of Fe + TiC composite powder.

2. Materials and experimental methods

The magnetic-abrasive finishing of the thread tap was carried out on a specially designed plant located in the CNC machines laboratory at the department of mechanical engineering of the Saint Petersburg Mining University. The MAF device was based on a CNC milling machine that provides all working movements necessary for the machining process.

M16×2 thread taps made of R6M5 quick-cutting steel were taken as pilot prototypes. A composite powder based on iron and titanium carbide (Fe + TiC) having various grain sizes $\Delta = 160 - 315 \mu\text{m}$ was used for forming a magnetic-abrasive brush in the work zone of the electromagnetic system. The following constant process factors were adopted for the magnetic-

abrasive finishing of the thread taps: magnetic flux density $B = 0.6$ T; polishing time $t = 210$ s; the thread tap rotation frequency in the work space of the electromagnetic system $n = 475$ rpm; thread tap advance along the pole tips $S = 120$ mm/min; machining gap between the pole tips and the thread tap $\delta = 1$ mm. The following parameters were used to control the condition of the contact surfaces of the thread tap teeth: cutting edge rounding radius ρ , μm ; roughness of the flanks, the front and the rear surfaces of the cutting teeth R_{a1} , R_{a2} and, respectively R_{a3} , μm ; microhardness of the rear surfaces of teeth H_v , MPa; the amount of material being removed Q , g.

The rounding radius of the cutting edges, the roughness of the flanks, the front and the rear surfaces of the thread tap cutting teeth were controlled with the help of a Hommel Tester T8000 profilograph-profilometer; microhardness was measured with the help of a PMT-3M microhardness tester; the amount of removed material, with the help of a VLTE 310 type scale.

The studies of internal thread cutting technology were carried out using a Trens SN 32/750 thread-cutting lathe. The workpieces undergoing the machining were made of 08Kh18N10T grade corrosion resistant material (metal thickness 40 mm). M16 $\times$ 2 mm thread taps were taken as cutting tools. These taps were preliminarily subjected to MAF with the purpose of creating various conditions of the contact surfaces of the tool teeth.

After cutting internal thread in a workpiece made of a corrosion resistant material using thread taps preliminarily subjected to MAF under various machining conditions, the roughness of the flanks of the internal thread profile was controlled. Roughness was controlled using a Hommel Tester T8000 profilograph-profilometer.

The experimental data on the roughness of internal thread surfaces were subjected to statistical analysis in the Statistica 10 software environment.

3. Results and discussion

As a result of the studies of magnetic-abrasive finishing of thread taps using Fe + TiC composite powder, it has been established that the magnetic-abrasive powder grain size Δ influences the condition of thread tap teeth contact surfaces, characterized by the cutting edge rounding radius ρ , the roughness of the cutting teeth flanks R_{a1} , that of their front R_{a2} and rear R_{a3} surfaces, the microhardness of cutting teeth rear surfaces H_v , and at the machining efficiency expressed in the amount of removed material Q (Fig. 4).

Analysis of the dependency curves presented in Fig. 4 allows to conclude that within the range of Fe + TiC composite powder grain sizes under study ($\Delta = 160 - 315$ μm), the thread tap cutting edges rounding radius after MAF varies within the range $\rho = 40 \dots 51$ μm , the roughness of tooth flanks $R_{a1} = 0,068 \dots 0,073$ μm , the roughness of tooth front surfaces $R_{a2} = 0,09 - 0,11$ μm , the roughness of tooth rear surfaces $R_{a3} = 0,095 \dots 0,149$ μm , the microhardness of tooth rear surfaces $H_v = 9,722 - 11,162$ MPa and the amount of removed material is within the range $Q = 6 \dots 8$ g.

The studies of thread taps MAF with the use of Fe + TiC composite powder having various grain size bear witness to a

substantial improvement of the condition of cutting tool teeth contact surfaces in view of the fact that originally the cutting edge had defects resulting from previous machining (Fig. 2), the tooth flank roughness was equal to $R_{a1} = 0,19$ μm , the tooth front surface roughness $R_{a2} = 0,26$ μm , the tooth rear surface roughness $R_{a3} = 0,26$ μm and the tooth rear surface microhardness $H_v = 7,507$ MPa.

Fig. 4. Fe + TiC composite powder grain size vs. the condition of thread tap teeth contact surfaces and the MAF efficiency curves: ρ – cutting edge rounding radius; R_{a1} – tooth flank roughness; R_{a2} – tooth front surface roughness; R_{a3} – tooth rear surface roughness; H_v – rear tooth surface microhardness; Q – the amount of removed material

4. ábra Fe + TiC kompozit por szemcseméret és a fúrőszerszám kontak felületének állapota, MAF hatékonysági görbék: ρ – vágóél lekerekítési rádiusz; R_{a1} – fog profil érdessége; R_{a2} – fog frontfelület érdessége; R_{a3} – fog hátfelület érdessége; H_v – fog hátfelület mikrokeménysége; Q – leválasztott anyagmennyiség

After the MAF of thread taps using Fe + TiC composite powder, experimental studies of internal thread cutting were performed. The thread taps used in this studies were previously machined by composite powder having various grain sizes in a magnetic field, and a dependency has been established between a change in internal thread roughness and the condition of thread tap teeth contact surfaces. Since condition is understood as a totality of microgeometrical parameters of contact surfaces of teeth, i.e. the cutting edge rounding radius, the roughness of cutting teeth flanks, front and rear surfaces, the microhardness of teeth rear surfaces and it is not possible to detect the dependency between the influence of each of these parameters on the internal thread roughness since during the MAF they are formed simultaneously, it was decided to plot the dependency curve in the following way: plot the thread roughness values on the ordinate axis and the composite powder grain size values that changed during forming of various conditions of thread tap teeth contact surfaces during the MAF, on the abscissa axis.

The dependency between changes in internal thread roughness and the condition of thread tap teeth contact surfaces presented in Fig. 5 allows to conclude that an increase in composite powder grain size from 160 to 315 μm during the MAF of thread taps is accompanied in the subsequent process of internal thread cutting using these taps by increased roughness of the profile of internal thread cut in workpieces made of 08Kh18N10T grade corrosion resistance material from 0.85 to 1.28 μm (R_a parameter). It should be noted that the roughness of internal thread cut by a thread tap that was not previously subjected to the MAF is 1.77 μm . The roughness of thread cut

by a previously MAF machined thread tap is reduced at least 1.4 times irrespective of composite powder grain size $\Delta = 160 - 315 \mu\text{m}$. This confirms the efficiency of using this finishing method within the framework of the parameters range under study.

Fig. 5. Dependency between changes in internal thread roughness (R_a) and the condition of thread tap teeth contact surfaces formed due to varying composite powder grain size

5. ábra Kompozit por szemcseméretének hatása a fúrószerszám fog kontakt felületének állapota és a belső menet felületi érdessége (R_a) közötti kapcsolatra

The studies of the MAF of thread taps using Fe + TiC having various grain size have shown that thread tap cutting edges rounding radius changes within the range of $\rho = 40 - 51 \mu\text{m}$ (Fig. 4). Since the cutting depth during thread tapping $a < \rho$, in this case the deterioration of internal thread roughness R_a parameter in workpieces made of 08Kh18N10T grade corrosion resistant material from 0.85 to 1.25 μm can be explained by elastic deformation of a workpiece surface layer in the process of cutting that has an adverse effect on surface microrelief formation.

Experimental data analysis allowed to conclude that within the Fe + TiC composite powder grain size range under study ($\Delta = 160 - 315 \mu\text{m}$) the most efficient MAF method for thread taps machining is using powder grain size $\Delta = 160 \mu\text{m}$ at magnetic flux density $B = 0.6 \text{ T}$ and finishing time $t = 210 \text{ s}$.

4. Conclusions

In conclusion, it can be said that using magnetic-abrasive finishing (MAF) during the machining of thread taps for the improvement of technology of internal thread surface cutting in workpieces made of 08Kh18N10T grade corrosion resistant material will allow to reduce the roughness of internal thread surfaces from $R_a = 1.77 \mu\text{m}$ (thread cutting by a standard thread tap) to $R_a = 1.28 - 0.85 \mu\text{m}$ (depending on the Fe + TiC composite powder grain size used during the MAF of thread taps).

Thus, the purpose of studies set by the authors (improvement of internal thread cutting technology by means of preliminary MAF of thread tap teeth contact surfaces) can be considered as achieved since internal thread profile flank roughness $R_a < 1.6 \mu\text{m}$ and within the range of $R_a = 0.63 - 1.25 \mu\text{m}$ in workpieces made of a corrosion resistant material is ensured.

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