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Preliminary communication

Investigation of the Reversal Loads in a Tapping Process

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Abstract: In the manufacturing industry, tapping tools are widely used for threading screws in drilled holes. It is expected that cutting loads would be affected by both the geometry of the tools and the cutting parameters in a tapping process. However, it is thought that such a simple mechanism does not exist. It is supposed that the tapping tools will encounter different loads while they are going forward and backward in the holes. Therefore, the unsteady loads that can lead to breaking the tools in the holes are important. In this study, tapping tests were performed on AISI 1050 steel. TiN-coated and uncoated HSS-E tools were used to cut M10 standard right screws on test parts. For this purpose, the test parts were thoroughly drilled with ø8.5 mm HSS drill bits. Then the tapping tools, which were manufactured in four different forms, were used to thread the screws in the holes. The tapping loads that are axial forces and torques were measured with a standard dynamometer. The experiments were carried out by using cutting fluid on a CNC milling machine. In conclusion, it is figured out that the axial forces and torques while the taps are going down the holes are more different than in the period the taps are going up the holes. While the tools were coming back at the end of the threading process the torques decreased, but the axial forces increased. Moreover, the heights values for the axial force and torque occurred by the TiN HSS-E tools that got straight-flute.

Keywords: AISI 1050; cutting force; tap; tapping; thread cutting

1 INTRODUCTION

Taps are cutting tools frequently used for threading in the holes on machine parts. Generally, tapping tools can be classified into two groups, such as machine and hand types. The machine taps that are preferred to be manufactured serially have got different forms and types [1]. Actually, the tapping process is more complex than a common machining process, for example turning, drilling, etc. Basically, it is similar to a drilling process (Fig. 1).

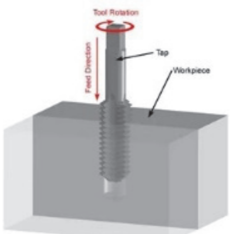


Figure 1 Tapping process [2]

Hard conditions, such as removing chip, lubricating cutting edges, determining the relationship between speed and feed rate according to screw pitch, make the tapping one of difficult operations. Moreover, many adversities like breaking taps, screw deterioration, etc. are encountered during the screw cutting. So, it is not forgotten that the taps should not be hard to work. Therefore, for proper tapping, tap selection and cutting conditions must be accurately identified [3]. Choosing the right tap and suitable machining parameters (feed, speed, coolant, etc.) affects the quality of the thread and the economy of the manufacturing. By the way, cutting tool manufacturers present the features of the taps in their catalogues. Although the characteristics of the cutters manufactured are generally similar, they may show some differences in their own characteristics. It is because each company manufactures the cutters on its own experience [4]. When literature is examined, it can be seen that the studies on the taps are done in recent years. In some studies, it has been stated that the cutting fluid used in tapping operation reduces the notch effect and flank wear on the taps [5]. It has been stated that ultrafine fluorine added to cutting fluid decreases the cutting forces as it reduces the friction coefficient by 18% with increasing temperature (400 - 455 °C) [6]. Furthermore, MQL systems are provided to decrease the torque in the tapping process [7]. It has been suggested that the abrasive and adhesive wear resistance of the TiCN-coated taps used for screwing in blind holes is better [8]. It is emphasised that the TiAlN and TiAlN/WC+C coated taps are better than other noncoated taps in threading process on GG25 material [9]. It has been suggested that the occurred axial forces during the process cause a change (increase, decrease) in the pitch of the screw. Thus, the axial forces should be reduced in order to minimize the errors on the screws [10]. Moreover, it is put forward that the forms of taps influence the tapping forces. Among the tested taps, the form, which is straight-flute and sharpened point with angle, creates lower forces than normal straight-flute taps [11]. In some studies, carried out with the taps, it has been observed that computer programs are also used. For example, in a study [12], a program is emphasised that evaluates instantly the measured shear force (F_c) values and predicts the blunting or breakage of the cutter. In addition, CAE systems were introduced to design and analyse the taps [13]. ANSYS methods were used to determine deformations of the taps as if in real experimental environment [14, 15]. Also, some statistical programs were performed to optimize the parameters used in tapping process [16].

When the literature is examined, it has been seen that there are few studies about the tapping tools. Further, in these studies, the forces and torques only that make the taps going forward in the holes to cut the threads, were investigated. But, the other loads occurring while the taps are coming back at the end of the tapping process, were not taken into account. It is generally supposed that the reversal loads produce no effects on the tapping process. Therefore, the reversal loads, such as the cutting forces and torques, were evaluated to determine the effects on the tapping process, in this study. The tests were performed on AISI 1050 material by using coated and uncoated taps, which are widely used in the market. The forces and torques were detected with a standard dynamometer for each of the forward and the backward movement of the taps. The loads are compared and evaluated to point out the effects on the tapping process. By the study would be made a contribution to select the correct taps and use the tools in tapping process well.

2 MATERIAL AND METHOD

In this study, an experimental work was performed by using tapping tools on AISI 1050 material. AISI 1050 material was preferred for threading tests, because the AISI 1050 is cheap, hardenable, has good mechanical properties, easy machinability, etc. Due to these properties, it is widely used in the entire manufacturing industry. The chemical composition of AISI 1050 material is given in Tab. 1.

Table 1 The chemical composition of AISI 1050 material / %

C	Si	Mn	P	S	Cr	Ni	Mo
0.53	0.29	0.88	0.03	0.01	0.25	0.18	0.09

AISI 1050 material, which is supplied as a bar from the market, was sliced in certain sizes and turned into 65 × 50 × 30 dimensions (Fig. 1). Experiments were performed to cut the metric screws (M10 × 1.5) by using HSS-E machine taps with different forms. The taps, which are the most widely used in machining sectors, were gotten from a market, stamped with a logo, Blau. 4 uncoated and 4 TiN coated HSS-E taps were chosen for the experiments (Fig. 2). The forms and some features of the machine taps were given in Tab. 2.

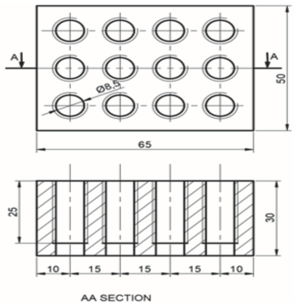
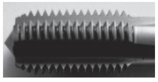
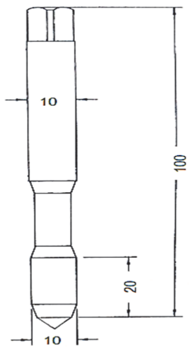
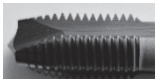
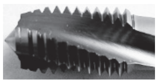
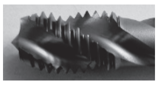


Figure 1 Technical drawing for the test parts

Figure 2 The TiNcoated HSS-E taps [4]

Table 2 Form and geometry of the taping tools [4]

<table>
<tr><th>Screw</th><th colspan="2">Tool Geometry (DIN 371)</th><th>Point</th><th>Flute Type</th><th>Tool Material</th><th>Tolerance</th><th>Dimension</th></tr>
<tr><td rowspan="4">M 10 X 1.5</td><td>Form C</td><td></td><td>-</td><td rowspan="2">Straight</td><td rowspan="4">HSS-E
TiN HSS-E</td><td rowspan="4">ISO 2
(6H)</td><td rowspan="4"></td></tr>
<tr><td>Form B</td><td></td><td>15°
Spiral</td></tr>
<tr><td>Form C</td><td></td><td>-</td><td>15°
Helical</td></tr>
<tr><td>Form C</td><td></td><td>-</td><td>30°
Helical</td></tr>
</table>

By the reviewed previous studies and the cutter catalogues, the hole diameter for machining the M10 × 1.5 screw is determined as ø8.5 mm [17]. Thus, holes on the AISI 1050 material were drilled by HSS drill bits, ø8.5 mm. A dynamometer, called Kistler 9272, which is presented in Fig. 3, was used to measure the loads in the tapping experiments. The dynamometer can be able to measure the forces (F_x, F_y and F_z) and the torque (M_z) and get 1000 data per second. But, the accuracy was preferred as 100 data per second to measure the loads in the tests. Also, the control program of the dynamometer can draw graphics for the measured loads.

A clamping apparatus was designed and manufactured to hold rigidly the test parts during drilling and tapping operation (Fig. 4). The tapping tests were carried out on a CNC milling machine tools (Fig. 5). The holes were thoroughly drilled in a certain order. The length of the screw was taken as 25 mm in the threading experiments (Fig. 2). It is known that feed rate for the cutting taps depends on screw pitch. Cutting speeds used with taps are kept lower than other metal removal methods. The reason for this is the sensitivity of the tap to breakage. In the experiments, AISI 1050 material, the taps with 4 different forms, single feed rate and single cutting speed were used. The reason of the preferred one feed rate and one cutting speed is to investigate the effect of the tools geometries on the cutting forces.

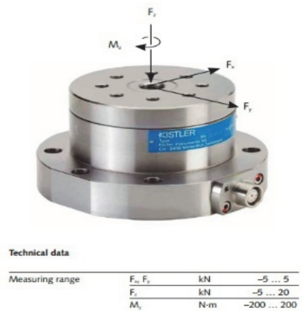
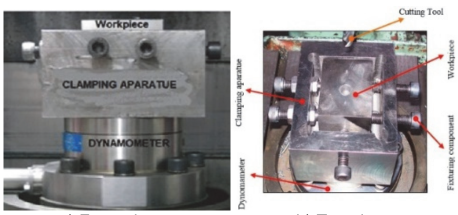


Figure 3 The used dynamometer in tests and measuring ranges [22]



a) Front view b) Top view

Figure 4 Clamping the workpiece in the experiment

Figure 5 The CNC machine tools were used in the experiments

The parameters and conditions in the tests are given in Tab. 3. For the parameters, normally, 8 tests (4 + 4) must be required to do this experimental work. But the experiments were repeated for reliability. So, a lot of experiments were carried out. All of the forces as F_x, F_y, F_z and the torque as M_z were measured during the tests.

An example graph for the measured loads, such as F_x, F_y, F_z and M_z, was given in Fig. 6. And a list for the values of the loads used in this graph is illustrated in Tab. 4. The values were obtained between 2.9 and 3.0 seconds in the test operated with the H4 tap. In Tab. 4, the F_x and F_y values are mostly very low compared to the F_z values. This state is clear in Fig. 6. Though, the curves of M_z and F_z is on the Y axis of the graph, the F_x and F_y is under Y axis. It is revealed that the most important force is F_z and torque is M_z in the process of the cutting screws [18]. In this case, it can be said confidently that the taps create very low forces in the F_x and F_y directions in time of the tapping. Moreover, in the literature reviews, it was seen that M_z and F_z were taken into account [19, 20]. In this study, the F_x and F_y were excluded from the evaluation of the test data. The evaluations were made by taking the arithmetic mean (Mean Value) of the values within the time limits determined precisely for the beginning and the end of the test. Finally, the evaluated tests results were given in Tab. 5.

Furthermore, names of the forces are written on the curves of the forces and torques in the graph (Fig. 6). And the directions of the forces (F_z) and torques (M_z) are illustrated on the given tap, used in the experiments. $F_{z_{in}}$ and $M_{z_{in}}$ occur while the tap is going in the hole. And, $F_{z_{out}}$ and $M_{z_{out}}$ are obtained by the tap that is going out of the hole. It can be seen that after approximately 4.7 seconds, the F_z and the moment M_z suddenly dropped vertically (circled). The pointed zone is where the tap starts to come back at the end of the screw. While the tap is coming back, it applies the axial force and torque to the part in opposite direction. If the F_z is examined for mechanic behaviour on the taps, F_z acts as a tension force and compression force. When the taps go down in the holes, a compression force causes the tap. In other words, F_z creates compressive stress on the tap. While the tap is going back in the holes, F_z operates as a tension force to the tap. F_z leads tensile stress on the tap. Furthermore, M_z is as a torsion force that generates torsional stress on the taps (Fig. 2).

Table 3 Test parameters

Tapping Tool				Test Material	Cutting Speed V / m/min	Feed rate f / mm/rev	Coolant	Drill Diameter ø / mm
Symbol	Tool Material	Flute Type	Point					
H1	HSS-E	Straight	-	AISI 1050	10	1.5	Bor Oil	8.5
H2			15^0					
H3		15° Helical	-					
H4		30° Helical	-					
T1	TiN HSS-E	Straight	-					
T2			15^0					
T3		15° Helical	-					
T4		30° Helical	-					

Table 4 Sample loads measured during tapping

Time / s	M_z / Ncm	F_z / N	F_y / N	F_x / N
2.9	667.114	7.32422	−4.27246	17.0898
2.91	646.973	14.6484	3.66211	11.7493
2.92	639.038	9.15527	6.40869	4.73022
2.93	637.817	15.8691	7.62939	−3.20435
2.94	637.817	19.5313	6.2561	−4.73022
2.95	638.428	18.3105	5.79834	−8.23975
2.96	651.855	18.3105	7.32422	−9.46045
2.97	651.855	18.3105	4.88281	−11.4441
2.98	628.052	28.0762	−0.457764	−20.2942
2.99	624.39	35.4004	−9.61304	−24.2615
3.00	629.272	31.7383	−15.564	−23.4985

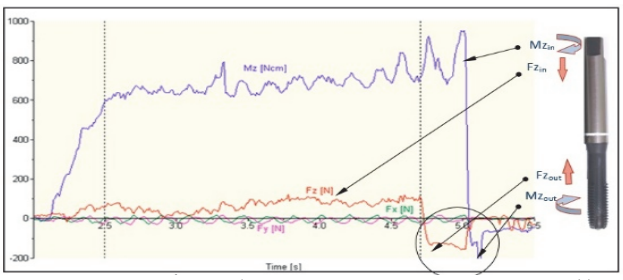


Figure 6 An example chart for the measured loads in the experiments [20]

Table 5 Test results

Tap	Tapping Loads			
	in		out	
Symbol	M_z / Ncm	F_z / N	M_z / Ncm	F_z / N
H1	818	95	357	121
H2	889	97	363	153
H3	601	108	250	114
H4	714	12	280	127
T1	1393	132	2335	317
T2	595	107	454	112
T3	959	60	360	170
T4	692	52	361	169

3 RESULTS AND DISCUSSION

To evaluate the test results some graphs were plotted, for example, M_z graphs are given in Fig. 7 and Fig. 8. Microsoft Excel was used to plot the charts. The charts were created separately for each tap group (coated and uncoated). Fig. 7 shows the M_z (torque) of HSS-E taps and Fig. 8 illustrates M_z for TiN HSS-E taps.

When Fig. 7 is examined, in general, it is seen that the M_z values are high when the tap is going down in the hole (phase for cutting the screws) and lower when it is coming back in the hole (phase for ending screw). When the M_z values are considered in terms of the tap forms, it was found that the H4 tap gave the lowest M_z values in both cases. It can be said that the tap with 30° helical flute creates the lowest M_z values, in other words, this tap has less difficulty in tapping process on AISI material. On the other hand, it can be thought that the most difficult tap is H1 (straight-flute tap), and due to its high moment value, this tap has a risk of breakage when it is threading on AISI 1050 material.

If the M_z graph given in Fig. 8 is examined, the M_z values are high when the taps are moving in the hole and lower when they are coming back in the hole. However, this is the opposite for the T1 cutter. The M_z value is higher as the T1 tap retracts in the hole. This can be explained by the straight-flute tap getting stuck in the hole. When the M_z values are considered in terms of the taps forms used, it has been revealed that the T4 tool gives the lowest M_z values in both cases. It is thought that this tap will be less difficult, since the 30° helical-flute tap causes the lowest M_z values when screwing in AISI 1050 material. Besides, it is understood that the most difficult tap is T1 (straight-flute), and due to its high moment value, there will be a risk of breakage when screwing this tap into AISI 1050 material.

Fig. 9 and Fig. 10 show the F_z forces respectively for HSS-E and TiNHSS-E cutters. Generally, in Fig. 9 it is seen that F_z values of the out position of the taps are higher than in position of the taps. In other words, the taps are forced normally when they cut the screws by moving down. However, they strain with more loads while they are coming back. It is known that F_z is an axial force that strains the taps for two types stress, such as tensile and compressive. The test results show that tensile stress is much higher than compressive stress on the taps. Considering the F_z values in terms of the tap forms used, it was revealed that the H4 tap leads to the lowest F_z values. It can be said that the tap with 30° helical-flute creates the lowest F_z values when it is returning in the holes. Therefore, it is figured out that this tap meets usually less difficulty when it is used on AISI 1050 material. On the other hand, it has been revealed that the most difficult cutters in the hole in both cases are H1 (straight-flute) and H2 (straight-flute and 15°). Thus, it is supposed that these taps get stuck while screwing into AISI 1050 material. For this reason, the thread profile can be deteriorated, and these taps may be a risk of breakage. However, there is an interesting situation here. Even though the H3 cutter had less difficulty when cutting the screws by going forward in the hole, it was hardly forced in the course of coming back.

Mainly, it is seen that the same situation is valid for graph 10, created for coated tools. Normally, the F_z values are low while the taps are moving through the hole. Further, the F_z loads are high during the coated taps return back. It is put forward that T2 is a better tool for tapping process. It has been found that the tap with straight-flute and 15° form is a preferred cutter for tapping process. Furthermore, it is seen that the most difficult tap is T1, which is exposed to high F_z force while moving in and out of the hole. It is thought that this tap will be more likely to break in the holes, because the F_z, as tension force, can cause the tensile stress on the tap.

By the way, the reversal loads of the coated taps are generally higher than the uncoated taps. The tests figured out that the uncoated taps were slightly better than the coated taps.

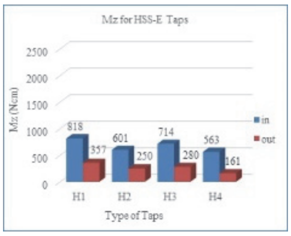


Figure 7 Graph of the M_z values for the uncoated HSS-E taps

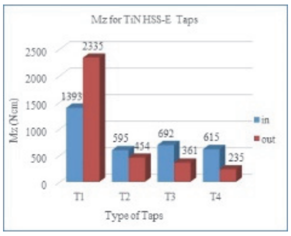


Figure 8 Graph of the M_z values for the TiN coated HSS-E taps

Figure 9 Graph of the F_z values for the uncoated HSS-E taps

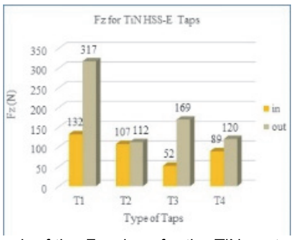


Figure 10 Graph of the F_z values for the TiN coated HSS-E taps

Some examples for the removed chips are given in Fig. 11. In Fig. 11a, the chip formed H2 tap because of that the tap's point was sharpened by 15°. This form is called a spiral-point somewhere. Via this form, these chips were pushed down the hole exit bottom of the part. The other chip (Fig. 11b) was obtained by H3 taps with helical-flute, 15°. This form pushed the chips up the hole exit on the part. Hence, these chips are rotated and pushed upwards in the helical-flute of the tap; the probability of the chips getting stuck between the tap and the hole wall is very high.

Many screws are threaded with taps on AISI 1050 material in the tests. It was observed in the experiments that some cutters were broken, although it is not very often. Especially, the H1 and T1 taps were broken, illustrated in Fig. 12. The straight-flute TiNHSS-E tap breaks when threading (indicated by an arrow). It is thought that the reversal loads, such as $F_{z\,out}$ and $M_{z\,out}$, in the tapping process cause the fault.

a) b)

Figure 11 Sample of removal chips obtained by H2 and H3

Figure 12 Sample of the broken tap in the hole

After the experiments were performed, the specimens were sliced by using a hack saw machine. Thus, it was ensured that the screws could be viewed more clearly (Fig. 13). Undesirable problems took place on the machined screw. For example, Fig. 13 shows that some teeth of the screws were deteriorated. It is supposed that high axial forces, which occurred in backward movement of the taps, lead to this fault in tapping process.

Figure 13 Sample of threaded screws

4 CONCLUSION

In this work, uncoated and TiN coated HSS-E tapping tools, 4 different forms, were tested on AISI 1050 material. The experiments were performed by using one cutting speed, one feed rate and coolant.

The experimental works pointed out that the thrust (F_z) force and torque (M_z) values are different for each of the forward and backward movements of the taps in the holes.

Mainly, the M_z values when the taps cut the screw in the holes are higher than while the taps are reversing in the holes. However, F_z loads, which occur when the taps are going down in the holes, are lower than while the taps are going up in the hole.

The experiments show that TiN coated HSS-E taps coded as T1, are not suitable for threading screws on AISI 1050 material because the huge values for F_z force and M_z torque occur by those taps.

The most suitable taps are T4 and H4 to decrease M_z, and F_z. It is understood that these tools should be preferred in tapping process on AISI 1050 due to the least risk of breaking.

Furthermore, researchers who will work with these cutters in the future are recommended that the screw forms are examined to determine the relation of the geometries of taps with the machined screws.

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