INVESTIGATION OF FORMING TAPPING LOAD CHARACTERISTICS USING ANALYSIS OF VARIANCE

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Abstract. *Threads are present in all assemblies of industrial products. Generally, mechanical components need parts threaded allowing assemblies with accuracy and quickness. Internal tapping is one of the most demanding machining operations, and threads obtained by cold form tapping are a good alternative. This work shows the influence of the hole's diameter and the forming speed during the cold form tapping. Trials were carried out with three diameters and three forming speeds. The material used was the AM60 alloy due to its ductility and applications industrial such as engine heads. The results are discussed according to the input parameters and the influence of them on responses. Torque and axial force were used as responses. The results showed that the hole's diameter variation has less influence on axial force and the torque than forming speed. The fill rate of thread profile according to diameter variation was negligible. Finally, the results demonstrated that the standard diameter of initial hole according to tool's supplier could be modified generating thread profiles more accurate.*

Keywords*: Form Tapping, Torque, Axial Force, AM60 Alloy.*

1. INTRODUCTION

Threaded joints always have been available in all kind of industrial devices being one of the most widely used solutions. All industrial products in need at least a threaded blind hole or threaded through hole to assembly a screw. The threaded parts production corresponds to an important stage in cells of manufacturing. Generally, tapping process is the last stage of the production and it needs good accuracy and finishing allowing an exact assembly without air-gap.

Considering internal threads, the most used process in industry to manufacture of these parts is the cut tapping. Cut tapping is a machining process, the thread results from chip removal. In case of form tapping, the thread is formed only by the displacement of the material work (Frometin et al., 2005). Several geometries of screw taps and coating are accessible for machining of all kind of metallic materials as well as non-ferrous and non-metallic. However, according to Fromentin et al. (2010) form tapping is process that has increased in industrial application in the last years. Although form tapping has existed for decades, very few studies have been published on the subject due to the poor interest on this process in industry (Chandra, 1975). Nevertheless, Fromentin et al. (2010) affirms that the interest in this process is growing, due to its specific characteristics and importance for the manufacturing industry.

Particularly the automotive industry has great interest on this process due to the possibility of elimination of steps for remove the chips of internal threaded. The no-generation of chips in form tapping is great advantage that it has on machining process. This occurs because during the form tapping, the screw thread is formed by displacement of the work material generating an almost perfect screw thread without wastes. The materials applied in automotive industry such as engine heads are manufactured with non-ferrous materials that have a great capability of accept strain without implicate in low strength. Baldo et al. (2010) studied form tapping in Aluminum alloy (Grade 7055) aiming define the tensile strength of internal threads. The work demonstrated that the form threads have the same resistance of machined threaded considering similar parameters such as pitch and diameter.

Magnesium and Aluminum alloys are non-ferrous materials applied frequently in automotive industry due to low weight, ease of work and possibility of recycling (Chowdhary, et al., 2002). Authors as Agapiou (1994) have developed several studies on form tapping. According to the author the smaller the hole's diameter greater the fill range of the thread with high torque during the process. Thus, a specific monitoring and control of the operation must be carried out in order to avoid tool breakage

Form tapping has some peculiarity as the appearance of a split crest at the top of the thread. crest depends on the hole diameter before form tapping. Considering the processes of manufacturing thread, external threads manufactured by the forming process are more widely used than internal threads. This is due to the screws that are most commercial with low cost of production allowing several models of pitch and geometric profiles with low productive time. According to Mathurin et al. (2009), forming threads are suitable for metallic materials highly ductile, mainly for internal threads used to transmit high loadings. Based on this, studies have been carried out only to define load based on experimental studies and mechanical models for torque calculation considering the finishing process. However, more studies must be carried out in form tapping aiming to define the values of torque, the split crest formation, surface hardness, and setting the perfect initial diameter based on each material making an accurate thread profile as well as thread forming screws.

The present study deals with the characterization internal thread obtained by the form tapping. The main variables are the coating of tooling, the hole's diameter, and forming speed. The torque, axial force, and rate of formation were analyzed as responses and compared using analysis of variance to define the most important value in form tapping.

2. EXPERIMENTAL SET UP

The experiments were conducted form tapping in flooded conditions on a ROMI Discovery 560 three axes CNC milling equipped with a maximum spindle speed of 10,000 rpm and 12.5 kW in drive motor.

2.1. Cutting tools and workpiece materials

The tools were form taps with code M10 6HX Druck-S provided by Emuge-Franken with diameter M10, picth 1.5, coating of TiN, and uncoated (Table 1). The tooling is according to standard DIN 13 and ISO standard for threads. Taps uncoated and coated with TiN had a polygonal form, but only the coated tap had five slots for lubrication, according to Fig. (2). Specimens of Magnesium AM60 alloy with 69 millimeters of diameter and 30 millimeters of height were manufactured, according to Fig. (1). Hardness of the specimens in three specific regions ranged of 65 to 74 HB in medium values.

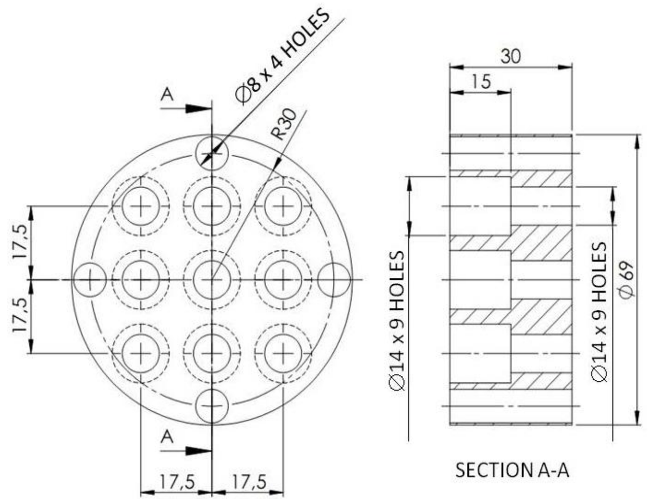


Figure 1. Scheme of specimen used in experiments

Table 1. The dimensional and mechanical properties of the tapping tool

Internal tool diameter [mm]	Pitch [mm]	Total length [mm]	Threaded length [mm]	Tool overhang [mm]	External tool diameter [mm]	Shank type	Coatings
9,35	1,5	100	16	39	10	Cylindrical	TiN/uncoated

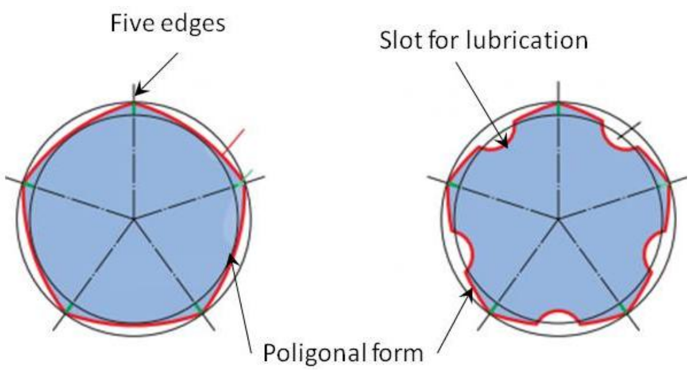


Figure 2. Transverse section of the form taps (Emuge, 2010)

2.2. Tapping conditions

For the purpose of investigation, the effect of tool's coating, forming speed, and hole's diameter the experimental tests were run at 18 different test conditions with three replicates. Aiming to optimize the experiments mainly the time, were carried out 9 trials of forming tapping in each specimen. The fixture of the specimens on the dynamometer was the simplest to avoid interference of intermediate devices. Thus, the specimens were fixed directly on the dynamometer as shown in Fig. (3). The rate formation of crest was measured using a microscope Mitutoyo model TM-500 connected in a computer, and a Moticam Solution MLC-150 digital camera.

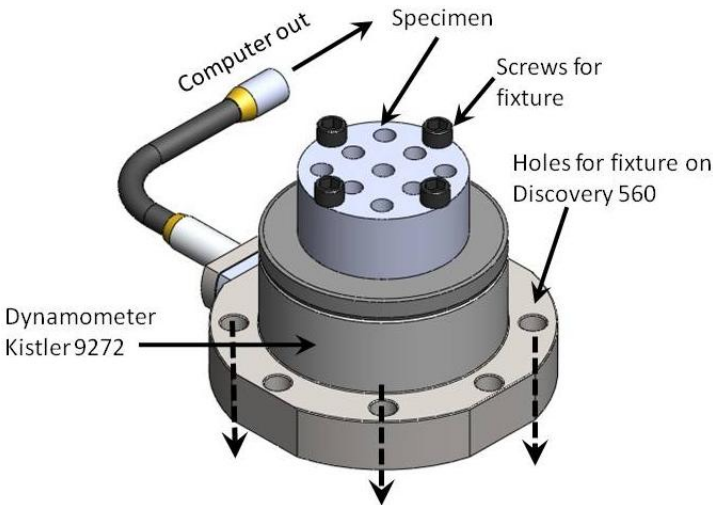


Figure 3. Assembly used in experimental tests

Analysis of experiments (ANOVA) was carried out to define the parameters of influence. The input parameters were forming speed, hole's diameter, and tool coating. The responses were torque, axial force, and the forming rate. Table (2) shows the parameters and theirs specific levels. The statistic analysis used the MiniTAB^{TM} software for ANOVA and the SISVAR was applied to define the influence of the interactions.

Table 2. Level of the input parameters

Input parameters	Level of the input parameters		
	- 1	0	+ 1
Diameter [mm]	9.1	9.3	9.5
Forming speed [m/min]	60	80	100
Tool	coated		uncoated

3. RESULTS AND DISCUSSION

3.1. Torque and axial force

Figure (4) shows a characteristic graph for axial force during the form tapping. We can observe that, the forming tapping is divided in three specific actions; the first correspond on the production of the thread, second represents the stop of tap in the end of the thread, and the last demonstrates the return of tool. The first part of graph represented in Fig. (4) occurs during the forming tapping, and it has two specific situations that start with the increase of force due to the conical part of the tap, and then occurs a constant axial force during the action of cylindrical region of the tap.

This situation occurred for all range of experiments changing only on the maximum axial force value. The begin of the second action, according to Fig. (4), is represented by a straight line that drops quickly until the minimum value of axial force. We can observe that the minimum axial force in return is bigger than axial force in tapping, considering the modulus of the values. According to the results we can support that, regardless of the forming speed used the graphs have the same behavior.

It occurred due to the coefficient of friction and the hardening of material during the process. The forming tapping uses materials that have a good formability, such as the AM60 Magnesium alloy, generating low efforts. However, in the return, the material formed not permits more strain due to dimensional characteristics of thread. Thus, the return of tap generates great friction and it increases the axial force value during the tap exit.

We can affirm that the axial force during the return was the same for forming tapping with both coated and uncoated tools. In the same way that occurs in full immersion of the tapping, the return also shows a proportional constant region with cylindrical part and a slope that corresponds to the exit of the conical part of the tap. The speed used in return was 20 m/min that corresponds to 1/3 of the forming speed during tapping.

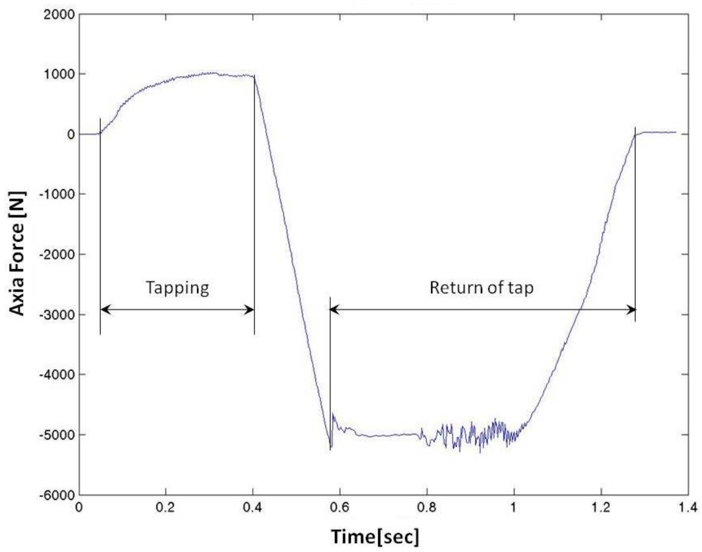


Figure 4. Experimental axial force during the form tapping
(Diameter 9.3 mm, forming speed 60 m/min and uncoated tap)

Figure (5) shows a graph that represents the behavior of the torque during the form tapping. We can observe that, in same way that occurred in axial force, the graph for torque has similar behavior with three regions. The first corresponds to the immersion of tap with a gradual increase for torque associated with conical and cylindrical. As observed in Fig. (4), the second part correspond to the stop of tap and the third the exit of him. The great difference of the torque is the relation tapping/return, because the value for return unlike what happened to the axial force has a proportional value to the tapping process. The exit of tap also shows a constant region and a quickly decrease for torque that corresponds to tap's geometry.

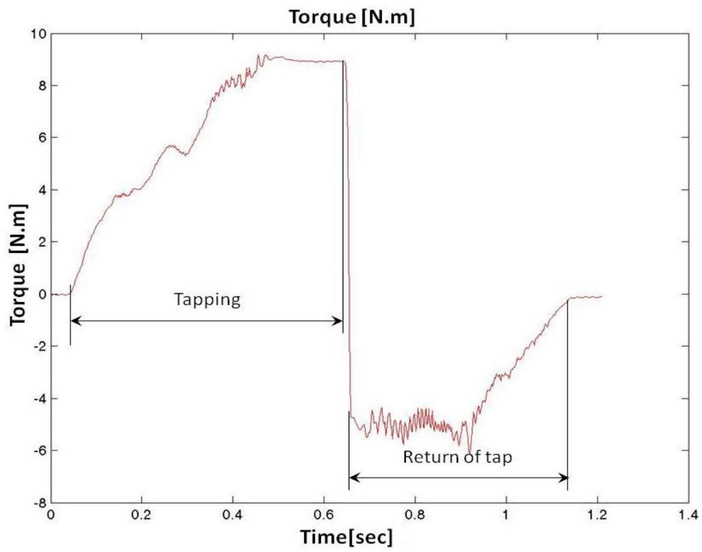


Figure 5. Experimental Torque during the form tapping
(Diameter 9.5 mm, forming speed 100 m/min and uncoated tap)

Thus, in summary, we can realize that the efforts during the form tapping for torque and axial force showed the same behavior. However, considering the return of tool the value are bigger for the axial force than the torque. It occurred due to rotation and axial displacement of tap. In other words, the rotation of the tool helps, at best the minimization of the efforts due to rolling attrition in interface tool/specimen, and generates values of low torque during the exit. On the other hand, the force during the exit of tap is measured only in axial direction and this condition not permits register low efforts of attrition.

3.2. Analysis of variance

Table (2) shows the analysis of variance for the output medium value. According to Werkema e Aguiar (1996), the values to P-value less or equal to 0.05 (95% of reliability) are considered significant, thus, its effects are showed in graph of interactions and main effects. The graphs of interactions and main effects compare the variations, considering the level of medium value, finding the values that have significant effect on responses.

Table 2. Analysis of variance (ANOVA).

ANOVA		P-value ≤ 0.05	
Mean factors	Experimental factors	Force	Torque
	Forming speed	0.000	0.081
	Hole’s diameter	0.000	0.000
	Tool	0.151	0.505
Interaction of factors	Forming speed* Hole’s diameter	0.451	0.357
	Forming speed*tool	0.138	0.297
	Hole’s diameter*Tool	0.014	0.006
	Forming speed*Hole’s diameter *Tool	0.080	0.628
	R2 (adjunct)	98.74%	79.76%

The R2 value in Table 2 represents the relation of preview in regression equation. The value closer to 1 (100%) demonstrates the equation adjusted to the data with best quality. Fig. (6) and (7) show the normal probability graph for the responses tested in experimental tests. The points on straight line are according to normality conditions required to validate the ANOVA model.

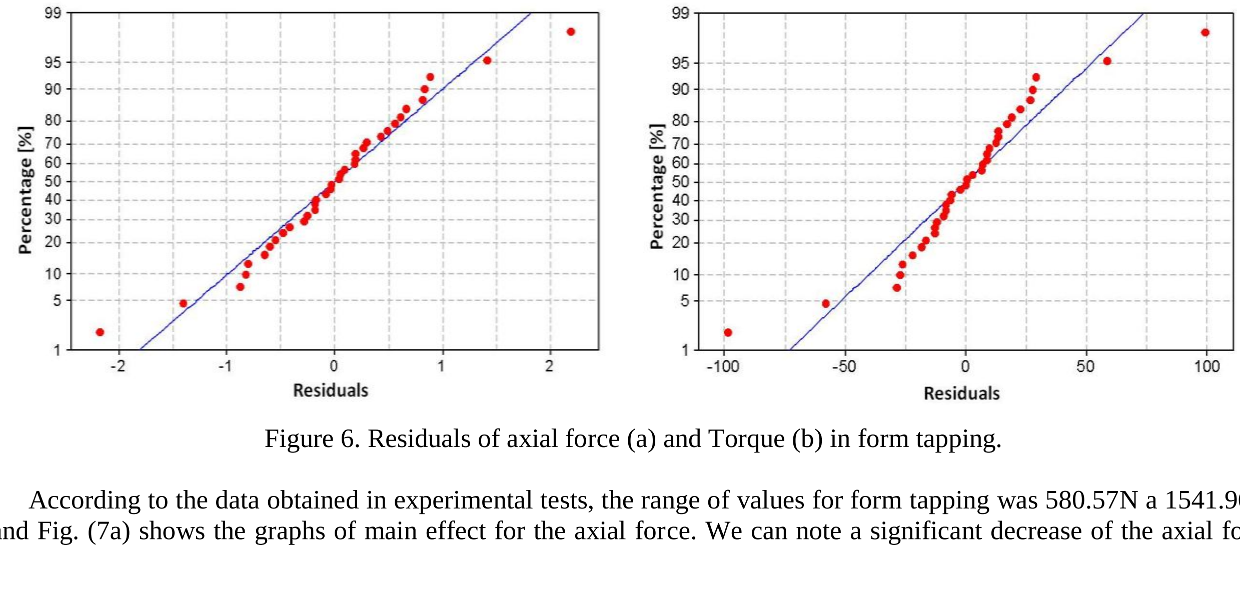
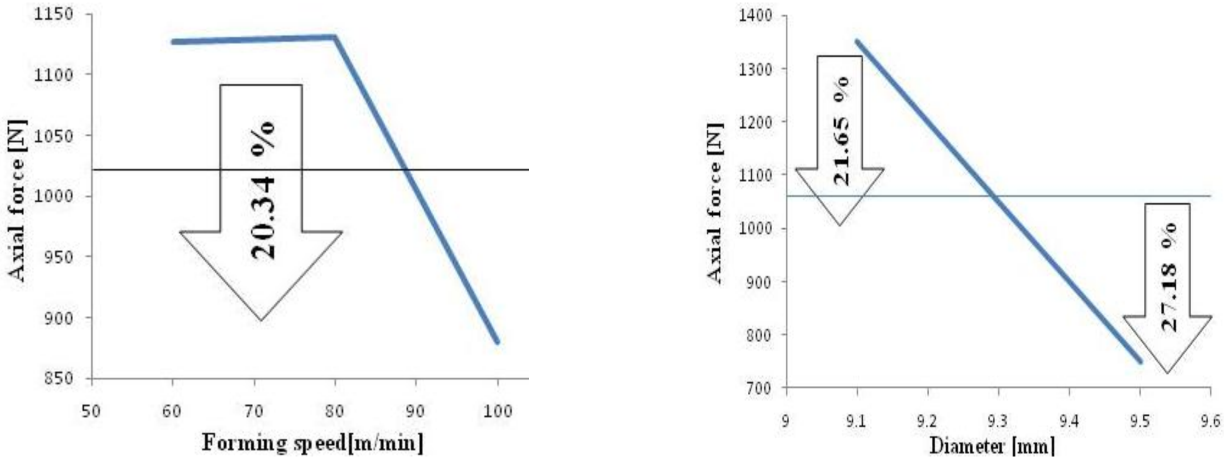


Figure 6. Residuals of axial force (a) and Torque (b) in form tapping.

According to the data obtained in experimental tests, the range of values for form tapping was 580.57N a 1541.96N, and Fig. (7a) shows the graphs of main effect for the axial force. We can note a significant decrease of the axial force for the forming speed of 100 m/min. The proportional medium value of reduction corresponds to 20.34% if we analyze the range of speeds between 80 and 100 m/min. Thus, we can consider that high forming speed generates more strain in ductile materials as AM60 alloy, being a good requirement for form tapping. The graph of main effects shows that the increase of diameter generates a decrease for the axial force in both levels tested, considering the influence of diameter on axial force, according to Fig. (7b),

Moreover, considering the range of 9.1- 9.3 millimeters, the decrease for the axial force was of 21.66%, and for the range of 9.3 to 9.5, the decrease was of 27.18%. Analyzing the effects of the diameter, we can define that in great hole’s diameters there is less mass of material for strain, thus we can support that this condition not generates high axial forces during the form tapping. If we considering the effects for the diameter and kind of tool in axial Force, according to Fig. (8), we can observe that for the diameter of 9.3 occurred a decrease of 5.11% in axial force, based on the variation coated and uncoated tool. However, for the diameter of 9.5 the decrease was of 8.03% for both tool’s coating. Finally, for the diameter of 9.1 the decrease was of 3.5% in axial force for coated tool when compared with uncoated tool. In this way, we can support that variations are strictly linked to tools geometry.



(A) (B)

Figure 7. Effect of the interaction of speed (a) and diameter (b) on medium axial force.

The coated tool has five slots used to lubrication during the process. Considering the diameter of 9.1 and the excess of material in hole’s diameter, we can note that occurred simultaneously strain and shear of the material generating chips, and this effect could be responsible to generate the increase of axial force. Considering the diameters of 9.3 and 9.5 a decrease of axial Force was observed due to the coating of TiN, because it has more friction coefficient than the uncoated tool. Furthermore, the uncoated tool geometry not has slots for lubrication during the process.

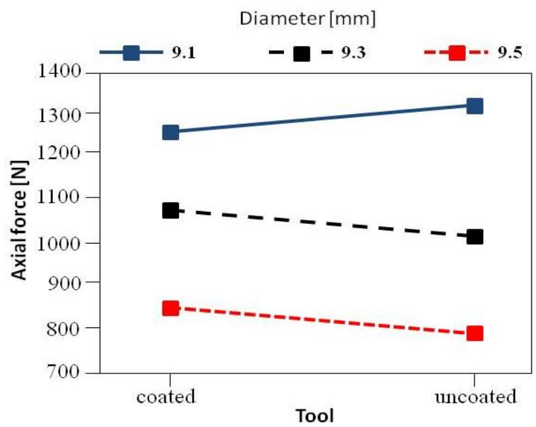
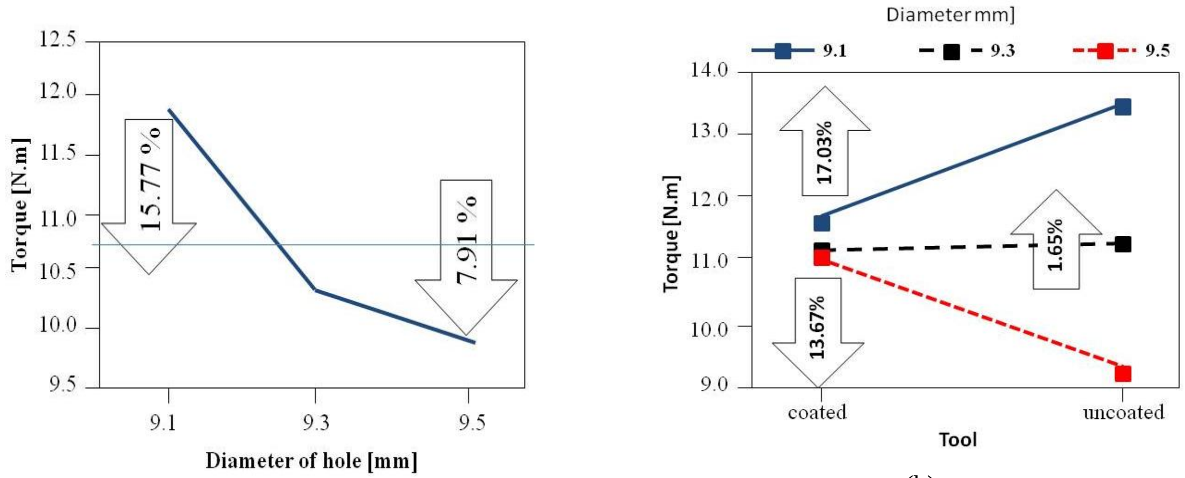


Figure 8. Effect of interaction diameter and tool on medium axial force.

The range for the torque values was of 6,9N.m - 15,39N.m. We can observe that diameter and the interaction between diameter and kind of tool showed effects significant, according to P-value of 0.000 and 0.006 in Tab. (3), respectively. Figure (9a) shows the graph of main effect of diameter on torque. We can see that the diameter decreases proportional to torque in three levels, and the decrease for the range of 9.1- 9.3 was 15.77% and for 9.3 - 9.5 was 7.91%. In the same way, which occurred with axial force can be observed in torque; the bulk of material to be formed has great effect on torque during the process. This effect was great for the diameter of 9.1 due to it is below of recommend by tool supplier, and thus it generates great value for torque. Considering the diameter of 9.5 this variation there is not significantly, because the torque values are below of medium and into the same range of work.

Figure (9b) shows the interaction of diameter with the kind of tool for experiments of torque, and we can observe that for diameter of 9.1 an increase of 17.03% occurred, comparing the coated tool with uncoated ones. Moreover, for diameter of 9.3 occurred a small increase of 1.65% for torque for coated tool to uncoated, and for diameter of 9.5 a decrease of 13.67% for coated tool for uncoated. We can note that the same way, in experiments of axial force the tendencies remained, with only a small variation to the diameter of 9.5, because it is showed a small increase in torque unlike the axial force that has a small decrease. In addition, the other values remained the same tendency for axial force and torque. Thus, we can define that the increase of hole's diameter generates small decrease of torque based on patterns recommended by supplier. This situation occurred due to the increase of volume since it directly proportional to increase of torque. On the other hand, uncoated tools are responsible to increase of torque more than the coated tools for diameters lesser than recommended by supplier.



(a) (b)

Figure 9. Effect of diameter (a) and interaction of diameter and tool (b) on torque

3.3. Analysis of fill rate

Table (3) shows the results of ANOVA for the medium values considering the analysis of the fill rate. The sources of variation in Tab. (3) are: VD = forming speed, DF = diameter variation and TF = kind of tool. According to the graphs of normal probability and histogram, the points show a straight line with a normal behavior required for the model.

Table 3. Analysis of variance for fill rate

Source of variation	Sum of square	Degree of freedom	Medium square	F_{calc}	P-value
VD	0.005039	2	0.002519	1.29	0.299
DF	0.421406	2	0.210703	107.9	**0.000**
TF	0.022003	1	0.022003	11.27	**0.004**
VD * DF	0.007894	4	0.001974	1.01	0.428
VD * TF	0.006672	2	0.003336	1.71	0.209
DF * TF	0.009606	2	0.004803	2.46	0.114
VD * DF * TF	0.005594	4	0.001399	0.72	0.592
Residual	0.03515	18	0.001953		
Total	0.513364	35			
R^2 (adjunct)	**93.15%**				

The range of values of fill rate was 0.3221 - 0,7948mm^2 for diameter of 9.1 millimeters and 9.5 millimeters, respectively. According to the Tab. (3) the diameter of hole's diameter and kind of tool have significant effect on fill rate, because the P-values were 0.000 and 0.005. Figure (10) shows the graph of main effect of kind of tool on fill rate. It can be noted that a decrease of 8.77% occurred in the fill rate considering coated tool and uncoated. We can define that, due the small difference found for coated and uncoated tool, a radial compression and an inefficient cooling system occurred simultaneously generating a cold work of material not generating a perfect profile of screw thread.

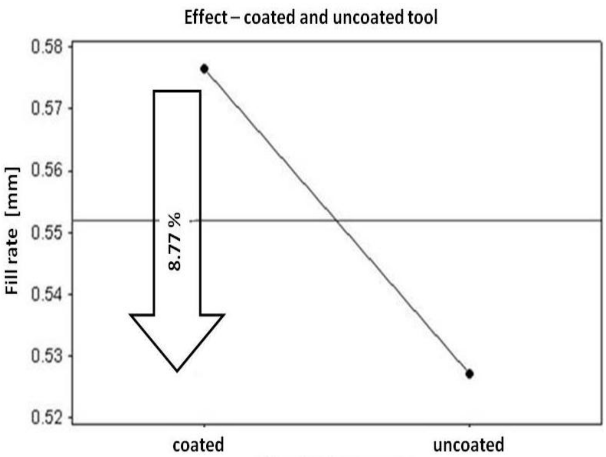


Figure 10. Effect of interaction of kind of tool on fill rate

Figure (11) shows the graph of main effect of diameter of hole on fill rate. We can note that occur a decrease of fill rate with the increase of hole's diameter. However, the decrease of fill rate was 14.92% in range of diameter of 9.1 - 9.3 millimeters and 28% in range of diameter of 9.3 - 9.5 millimeters. Thus, we can support that small holes have a maximum amount of material to be deformed. Based on this, the threads formed have a profile more complete than the great hole's diameter, showing a profile closer of standard profile generated by cutting taps.

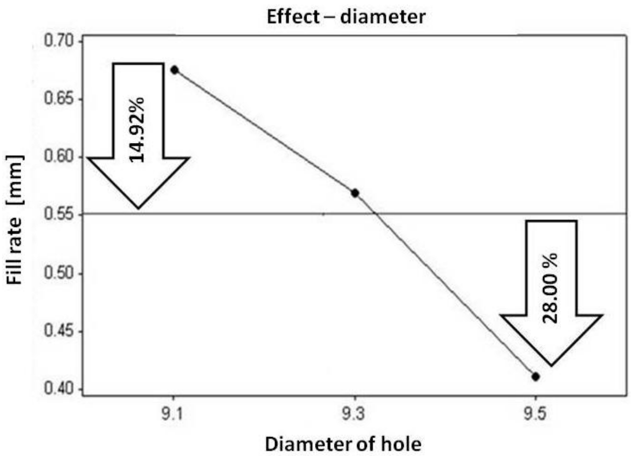


Figure 11. Effect of diameter of hole on fill rate

4. CONCLUSIONS

According to results, the following points are summarized:

- ✓ The holes's diameter showed significant effect for both properties evaluated, a decrease of torque and axial force can be observed for increase of diameter;
- ✓ The forming speed also showed significant effect on axial force, because was observed a decrease of axial force in speed of 80 m/min for 100 m/min;
- ✓ The interaction of forming speed, hole's diameter, and kind of tool showed significant effect for both evaluated properties. Thus, if we consider the axial force and torque we can affirm that:
- ✓ The axial force showed a decrease in diameters of 9.3 and 9.5 with coated tool to uncoated tool. However, an increase of force was noted for diameter of 9.1 for coated tool when compared with uncoated tool;

- ✓ An increase of torque can be observed in diameter of 9.1 when compared coated tool and uncoated, and also a low increase of torque in diameter of 9.3 of coated for uncoated. In addition, it was observed a decrease in torque for the diameter of 9.5 for coated tool when compared uncoated tool.

5. ACKNOWLEDGEMENTS

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