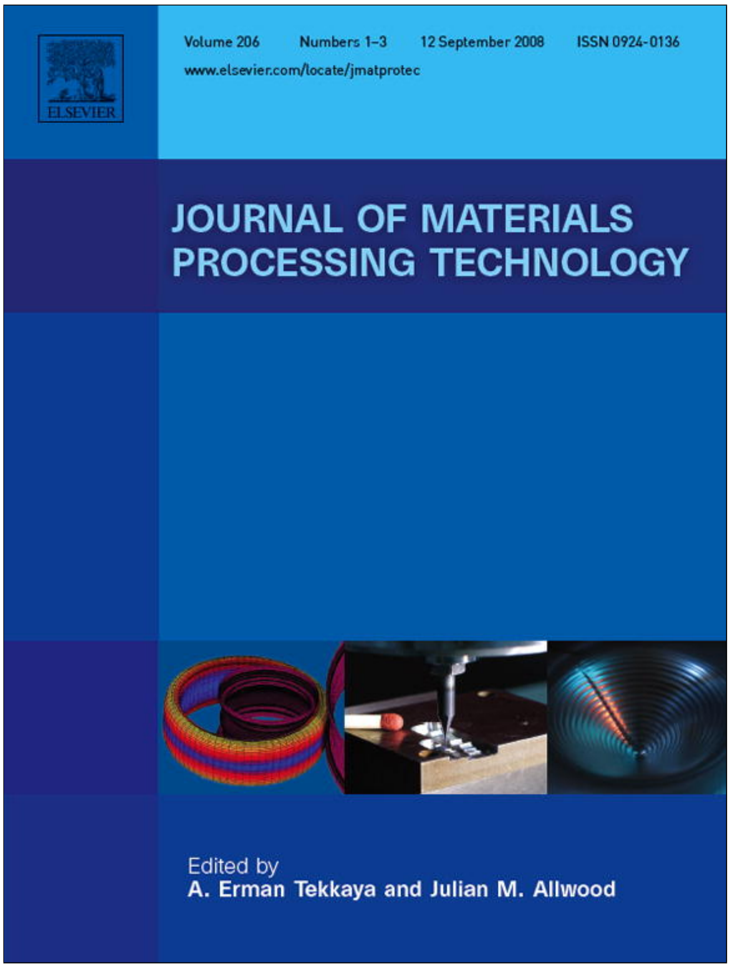

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A smart stamping tool for punching and broaching combination

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ABSTRACT

The crescent search for production time reduction is a factor that stimulates the improvement of the existent manufacturing techniques. In this work, a combined process using tools that perform punching followed by broaching in only one operation is studied in order to obtain holes with improved precision and surface finish. This researched combo process should make possible the manufacturing of pieces in less time with better use of material and equipment. This allows the use of only one process for heavy-duty jobs on thick sheet metal. In order to study this process, eighteen tools with three types of geometry with parallel and nonparallel cutting angle were made. Tool lubrication/cooling conditions were also analyzed using cutting fluids with concentrations of 100, 75 and 50% Hislip with respective 0, 25 and 50% of water. The hole final surface roughness, diameter and conical form, cutting tool angles, tool temperatures and cutting tool degradation were analyzed. The data obtained through the analysis of the variance (ANOVA), showed that this process is viable due holes obtained with overall superior quality, when compared with the ones generated in conventional stamping processes. Holes produced by tools types I, II and III presented good results in the holes overall precision. Nevertheless, in general, the best results were seen using tools type I, with punch angle of 22.5° and, lubrication/cooling conditions using 75% Hislip concentration as cutting fluid (water emulsion).

1. Introduction

The sheet metal cutting operation is a part of the stamping process, and it is understood as an important factor to keep the quality of the produced pieces (Waurzniak, 2002; Hilditch and Hodgson, 2005a, 2005b). In an ideal punching operation the punch tool penetrates the material to a depth of approximately 1/3 of the sheet thickness before the material fracture. The material proportion that penetrates the die has polished aspect. In this sense, Hambli and Potiron (2000) studied the process parameter's variation effects on the tool cutting geometry and the evolution of the punching tool penetration. Cracking initiation and propagation could be foretold and the experimental results agreed with the computer simulated ones.

The productivity and quality of the metallic sheet cutting process can be evaluated through the burr height observed at the material corners (Hambli, 2002). According to Luo (1997), the useful life of a punching tool could be evaluated observing the metal chips characteristics, analyzing the heights of them and the scrap section profile.

The punching tools geometries are responsible for its performance during stamping and the cut angle is one of the fundamental elements of optimization. Kalpakjian (1997)

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shows that punching tools with sloped cut front faces can reduce cutting forces between 35 and 50%. Singh et al. (1992) modelled through finite elements several types of punching tools, with and without angles, and observed that the smallest variations of radial deformation were observed in tool tips with V angles up to 45°. For the punching tool optimization purpose it is said that when the cut angle is of 22.5° the radial deformation is practically null.

Broaching is a process of internal or external linear machining, which makes possible to obtain regular or irregular surfaces through rough or finish machining operations, or even smooth surfaces in a single pass. The compression broaching tools could be used to give the final finish in holes produced by drilling or enlargement. Broaching is a process that also could produce holes in all geometric forms. According to Mo et al. (2005) the broaching tool executes a sequence of simultaneous machining operations, in which, several teeth can be acting in the same instant. In the course of time, cost analyses proved that broaching is the most efficient and economical machining process available for holes of any geometric forms (Groover, 1996). During broaching, the multi-cutting tool executes a linear movement, while the piece stays static. The degree of superficial finish obtained through this process is about 0.4–12.5 μm Ra. According to Klocke and Konig (2007), in broaching operations, cutting speeds used are considered relatively small when compared with other machining processes and also low tool wear is observed. Considering lubrication/cooling systems for machining with the use of higher cutting speeds, the cooling effect is more important than the lubrication. Following this idea, Shaw (2005) considered lubrication for broaching processes more important than cooling as it uses low cutting speeds.

This work shows a practical study that tries to evaluate the viability of a combined tool of punching and broaching. The objective was to obtain cylindrical holes on thick sheets with good dimensional quality and surface finish. With this new combo process, it is possible to ally the stamping job shop flexibility, and the good capabilities of the broaching process getting faster speed in producing holes in heavy-duty jobs with fine tolerances.

The main motivation for developing this new process is the elimination of a problem that happens during the punching of sheets thicker than 6.0 mm (Luo, 1997; Faura et al., 1998). When sheets of that thickness are punched the blow-out effect happens. In other words, the punched holes became conical (Altan, 1998; SME, 1990). The smaller diameter corresponds to the initial contact area of the punch with the sheet and the larger diameter is generated by punch withdrawal. In this case, the diameter in the exit of the punch becomes larger than projected. Analyzing the scrap (sheet slug) a difference in diameters is clearly observed.

The blow-out effect became worse with the increasing of the material hardness and mainly with the increase of the stock thickness (Klein, 2002). The traditional solution to avoid that problem would be to submit the sheet to a conventional process of reaming or enlargement after drilling. However, these operations demand additional time (Shaw, 2005; Klein, 2002). Furthermore, it also involves an application of other machines and tools, making the process slower and more expensive. Another solution would be to make holes by laser process that would allow obtaining pieces with parallel holes. Steeg (2002) shows combined machines of laser and punching which associates the laser flexibility with the punching productivity, but this process is still much more expensive when compared with conventional stamping process. Little information about combined tools of punching and broaching could be found in technical literature. In the Society of Manufacturing Engineers (SME, 1990), it is a descriptive on dies for broaching slots in a round shaft. Mello and Marcondes (2006) showed this new stamping tool of punching and broaching process composed basically by punch and die, Fig. 1. In this process, the traditional punch was endowed with broaching teeth. Mello and Marcondes (2006) studied some diameters of the punches and geometric form of the teeth used for broaching. In this study, several items were analyzed in order to identify the main variables and their process influences, i.e. geometry of the tool, the surface roughness, hole diameter, hole conic form, tool angle, temperature and visual tool degradation. The roughness and the level of metal chip generation were also analyzed.

2. Experimental procedure and techniques of analysis

In order to study the viability of this new combined tool for punching and broaching, some variables of control were selected: geometry of the tool broaching area, with or without tool angle and lubrication. The geometries and lubricant concentrations were studied in three levels, which were I, II and III for geometries and 100, 75 and 50% for oil concentrations (water emulsion). The tool angle was studied in two levels (with and without). Finally the measured variables were: diameter, hole conic form, hole roughness, temperature in the middle of the broaching segment and visual tool degradation after 100 holes.

The variation of the hole's final diameter and conic form was chosen because it was an indication of the hole precision; the roughness for being an associated parameter of the hole's quality and, the temperature, for being associated with cutting conditions (as well as the useful tool life). In order to facilitate the experiment's identification a code was created to identify the stamping and broaching conditions.

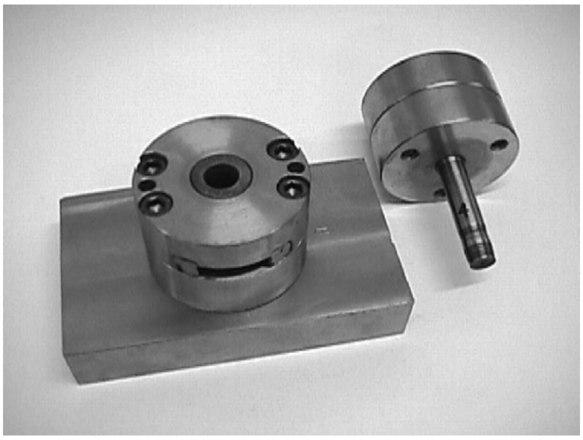

Fig. 1 – Tool set for punching and broaching combination.

Table 1 – Variables and level of experiments

Number	Codification	Description
1	PIS100	Punch type I – without point angle – Hislip's concentration (100%)
2	PIIS 100	Punch type II – without point angle – Hislip's concentration (100%)
3	PIIIS 100	Punch type III – without point angle – Hislip's concentration (100%)
4	PIS75	Punch type I – without point angle – Hislip's concentration (75%)
5	PIIS75	Punch type II – without point angle – Hislip's concentration (75%)
6	PIIIS75	Punch type III – without point angle – Hislip's concentration (75%)
7	PIS50	Punch type I – without point angle – Hislip's concentration (50%)
8	PIIS50	Punch type II – without point angle – Hislip's concentration (50%)
9	PIIIS50	Punch type III – without point angle – Hislip's concentration (50%)
10	PIC100	Punch type I – with 22.5° cutting angle – Hislip's concentration (100%)
11	PIIC100	Punch type II – with 22.5° cutting angle – Hislip's concentration (100%)
12	PIIIC100	Punch type III – with 22.5° cutting angle – Hislip's concentration (100%)
13	PIC75	Punch type I – With 22.5° cutting angle – Hislip's concentration (75%)
14	PIIC75	Punch type II – with 22.5° cutting angle – Hislip's concentration (75%)
15	PIIIC75	Punch type III – with 22.5° cutting angle – Hislip's concentration (75%)
16	PIC50	Punch type I – with 22.5° cutting angle – Hislip's concentration (50%)
17	PIIC50	Punch type II – with 22.5° cutting angle – Hislip's concentration (50%)
18	PIIIC50	Punch type III – with 22.5° cutting angle – Hislip's concentration (50%)

The first code corresponds to the punch type and it can be PI (Punch tool type I), PII (Punch tool type II) and finally PIII (Punch tool type III). The second code corresponds to the tool angle and it can be S (for tools without angle) and C (for tools with angle). Finally the third code corresponds to the lubricant concentration (Hislip) in the water emulsion that could be: 100 (100% of pure Hislip), 75 (75% of Hislip) and 50 (50% of Hislip).

Table 1 shows the test's identification followed for the experiment description. The sequence of the experiments was made to avoid bias. Quantitatively, the experiment consists of a $2^1 \times 3^2$ factorial, in other words, it is constituted by 18 tests according to the Table 1.

Fig. 2 illustrates the tools dimensions with geometries I, II and III. Geometrically the tools were 100 mm length and had 8.8 mm in diameter. A clearance between tool diameter and die of 1.2 mm was left. This value is consistent with the traditional punching process for thick sheets (SME, 1990). Broaching teeth height (*h*) are equal to the cut depths (asf) varying from 0.025 to 0.15 mm. These values are consistent with the traditional broaching cut depths with penetration from 0.03 to 0.08 mm for rough machining. Teeth distances from each other are about 1 mm, with a total length for broaching that varies from 8.0 to 13.9 mm (depending on the tool type). The maximum broaching length was projected to be the smallest as possible due to the machine limitations (the machine needs a simultaneous use of this combo tools and the standard punching tools). The tools have a space of 3.4 mm from the cutting edge extremity to the beginning of the broaching teeth (assuring punch penetration of 1/3 of the sheet thickness). The tool geometric differences were in the broaching segments and teeth:

- Punching tool I: tool with progressive teeth in the cutting direction (one cutting segment).
- Punching tool II: tool with progressive teeth in cutting and withdraw direction.
- Punching tool III: tool with progressive teeth in the cutting direction in two segments (2×).

The tool angle chosen was 22.5°, this angle induce less cutting forces and reduced radial deformation. The punch and dies were manufactured of VF 800AT steel (quenched-hardening and temper). All tools were produced from the same raw material and heat treated together. The three complete tools sets are described in Eto (2005). These tools were fixed at a base 40.0 mm thick with two columns of 35.0 mm in diameter (the objective was to increase the process stability and the die/punch alignment).

The sheets used in these tests have the following specification: NBR 6656 LNE 38 strips, 8.0 mm thick. The strips were obtained from sheets of the same rolling lot. In the sample pieces used, 1800 holes were made (18 punching tools × 100 holes with each one) using a mechanical press with capacity of 100 t (La Mundial—type C), 30 strokes per minute.

The stamping speed used was 6.0 m/min, which follows the standard values for broaching cutting speeds (from 6.0 to 10.0 m/min for steel) (Klocke and Konig, 2007). This speed is adequate for both processes (punching and broaching).

3. Techniques of analysis

In this section it is described the techniques that were used to characterize the hole overall precision, such as, conic form and roughness.

3.1. *Geometric characterization of the holes*

The hole conical form and diameters were measured using a manual digital Mitutoyo vernier caliper with 0.01 mm resolution. The results showed in Table 1 are the average of the last five holes, in other words, holes from 96 to 100 of each strip in every one of the 18 experiments. The diameters presented in these results were the tool entrance diameter. The conic form of the holes corresponds to difference between the entrance and exit diameters.

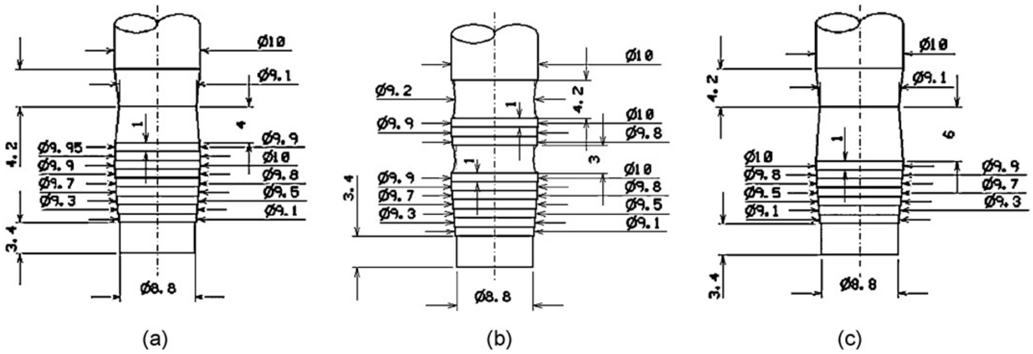

Fig. 2 – Punch tools geometries: (a) punch tool type I and (b) punch tool type II and punch tool type III.

3.2. *Surface finish of the holes*

The surface finish of the holes was analyzed in terms of roughness (R_a) and the superficial aspect inside the holes. Roughness results were recorded as averages of five measurements being done using a roughness machine Mitutoyo SJ-201. The measurements were done inside the holes with cut-off of 0.8 mm (moving the sensor in the same direction of the punching tool movement).

3.3. *Tool temperatures*

Tool temperatures were obtained through an optical thermometer Rayteck-st. Tool temperatures were measured in the middle of the broaching section after stamping the 100th hole for each one of the experiments.

3.4. *Data analysis*

The data were analyzed with Statistic software modulates switcher. Analysis of the variance (ANOVA) was used to identify which variable presented significant statistic difference. However although ANOVA identifies inequalities between the mean values it does not identify which mean values are different. It becomes necessary to apply a multiple comparison test. The least significant difference (LSD) test uses the student distribution of probability (t) with 95% degree of confidence to compare mean values differences (Devore, 1995). The tests of multiple comparisons LSD were used with trust of 95% to analyse which mean values were statistically different.

The analysis of the variance was applied for the null hypothesis test in which all of the mean values are the same. This could identify at least one of the mean values different from the other.

The analysis of mean values significance was made on statistics F (relationship of the medium squares—of the treatments and residual) and about the factor p. In these cases as larger the factor p as closer the experiment reaches the null hypothesis. Therefore, a factor p about 5% was adopted to help identifying mean value with statically significant differences among the factors (Scheaffer and McClave, 1996).

4. Results and discussion

In Table 2 the hole surface roughness, the hole diameter, the hole conical form and the cutting temperature data in function of the studied variables are presented (tool type, punch angle and lubrication concentrations of cutting fluid).

The ANOVA for roughness, diameter, conical form and temperature are presented on Table 3a–d, respectively (SS = square sum's, d.f. = degree of freedom, MS = medium square, F = tests statistics, 1×2 = interaction between 1 and 2 or interaction between the angle and the punch tool E_p = exact value of the level of significance for a test statistics).

Table 3 indicates that just the tool angle had a significant impact for the surface roughness (with significance of 95%). For the hole diameter the significant variables were tool angle and cooling. For the hole conical form, the tool angle and the tools geometry were significant. The interactions between tool angle versus tool geometry and tool angle versus cooling also show some significance. For tool temperature, the significant variables were tool angle, cooling and their interactions. Exemplifying it could be said that, in order to control or change the tool temperature the effective variables are tool angle, cooling and their respective interactions.

4.1. *Influence on hole surface roughness*

The Fig. 3 shows the surface roughness results in function of the variable punch angle. It is verified that the inclusion of angle induces the hole finish for a mean roughness value with a smaller dispersion. Probably this happens because the smaller radial deformations generated through the use of a 22.5° angle and less chip adherence on these types of tools.

Initially these results showed great influence in surface roughness for this punching and broaching combined process. In a second analysis, even the surface roughness generated for the broaching tool segment was inside the expected surface roughness for a traditional broaching operation. This result shows that broaching, as final machining operation is who define the process surface quality. However the hole already obtained, by punching, had superior surface quality in the beginning. When tools with angles were used for punching, the surface finish inside the holes seems to have better results. In short, the punching tools with angle gen-

Table 2 – Collected data (hole surface roughness, hole diameter, conical form of the holes and tool temperature)

Item	Types	Angle	Punch	Cooling/ lubricating (%)	Roughness (R_a)	Diameter (mm)	Conical form (mm)	Temperature (°C)
1	PIS100	Without	I	100	1.69	9.97	0.09	187
2	PIIS100	Without	II	100	0.33	9.98	0.04	195
3	PIIIS100	Without	III	100	2.12	9.99	0.05	195
4	PIS75	Without	I	75	0.75	10.00	0.09	170
5	PIIS75	Without	II	75	0.29	9.99	0.07	167
6	PIIIS75	Without	III	75	0.44	10.01	0.04	188
7	PIS50	Without	I	50	1.72	10.02	0.08	177
8	PIIS50	Without	II	50	0.61	10.02	0.02	195
9	PIIIS50	Without	III	50	0.68	10.00	0.01	187
10	PIC100	With	I	100	0.24	9.99	0.09	187
11	PIIC100	With	II	100	0.27	9.98	0.06	203
12	PIIIC100	With	III	100	0.55	9.98	0.08	193
13	PIC75	With	I	75	0.25	9.99	0.08	165
14	PIIC75	With	II	75	0.28	9.99	0.07	151
15	PIIIC75	With	III	75	0.3	9.99	0.07	164
16	PIC50	With	I	50	0.45	9.99	0.10	165
17	PIIC50	With	II	50	0.28	9.99	0.08	164
18	PIIIC50	With	III	50	0.62	9.98	0.08	148

erated holes with roughness in the order of 0.18–0.70 μm R_a. Therefore, the superficial quality expected to be generated by broaching was not only driven by machining, as different types of tools and lubrication/cooling fluid concentrations did not show significant influence in surface roughness, which are factors that could appear to have influence in broaching (Table 3a).

On the other hand punching tools of type I, with progressive teeth in punching direction of cut (Fig. 2a), and Hislip concentrations of 75 and 100%, presented the smallest surface roughness mean values and dispersions. Possibly, this was due to the tool geometry, which allows cutting without interruptions (which did not happen with the punch tools of the types II and III).

4.2. *Influence on hole diameter*

According to ANOVA (Table 3b) it was observed that the punching tool angle and lubrication/cooling had influence in the holes diameter results. Hole diameter versus punch angle values are showed in Fig. 4. The hole diameter mean values obtained with tools without angle are around 10.0 mm. Nevertheless, the dispersion values obtained for hole diameters are smaller for tools with angle. Therefore the tool is more adequate for production. It was still observed that, the stamped hole mean diameter with non-parallel punch angle approached enough of the nominal diameter of 10 mm, but a larger dispersion in results was observed.

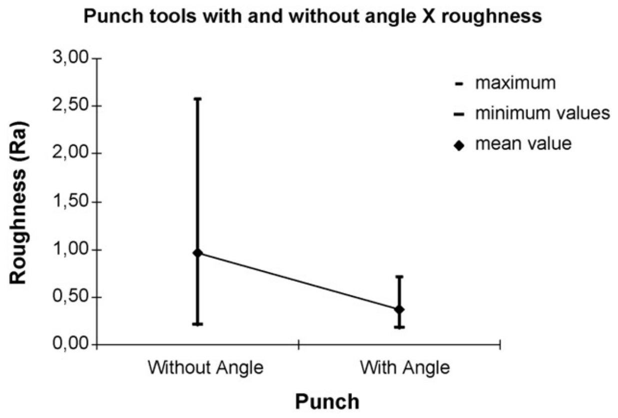

Fig. 3 – Roughness versus punch angle.

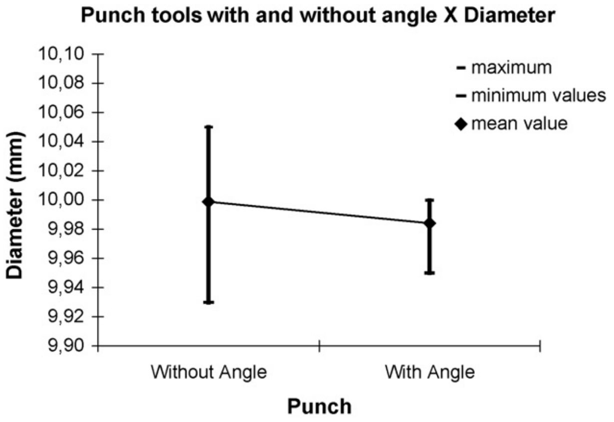

Fig. 4 – Diameter versus punch angle.

Briefly, the tools with angle can produce holes with larger dimensional stability (reproducibility) when compared with holes made by punching tools without angle. A diameter variation of 0.05 mm for tools with angles against 0.12 mm for the holes generated by punching tools without angles was obtained. Possibly, this happened due to the smaller radial deformation, as mentioned by Singh et al. (1992).

Despite ANOVA tests, as shown in Table 3b, lubrication/cooling concentrations also showed influence on the hole diameters. The average diameter value variations suffered small variations in the order of 0.02 mm (maximum variation of 0.06 mm). This value can be practically ignored by practical uses. It was observed that for tools with smaller oil concentrations, in the emulsion, the mean value diameter variation

Table 3 – ANOVA for: (a) roughness; (b) diameter; (c) conical form and (d) temperature

(a) Var.: RA1; $R^2 = 0.70252$; Adj: 0.43809 (análise7.sta) (1) 2-level factors, (2) 3-level factors, 18 runs – DV: RA1; MS residual = 0.1849051

ANOVA/roughness	SS	d.f.	MS	*F*	*p*
(1) Angle	**1.614006**	**1**	**1.614006**	**8.728832**	**0.016104**
(2) Punch	0.912011	2	0.456006	2.46616	0.139954
(3) % Cutting fluid	0.736678	2	0.368339	1.992043	0.192194
1 × 2	0.175208	1	0.175208	0.947558	0.355776
1 × 3	0.168033	1	0.168033	0.908754	0.365345
2 × 3	0.324012	1	0.324012	1.752318	0.218222
Error	1.664146	9	0.184905		
Total SS	5.594094	17			

(b) Var.: D1; $R^2 = 0.81517$; Adj: 0.65088 (análise7.sta) (1) 2-level factors, (2) 3-level factors, 18 runs – DV: D1; MS residual = 0.0000759

ANOVA/diameter	SS	d.f.	MS	*F*	*p*
(1) Angle	**0.000729**	**1**	**0.000729**	**9.607139**	**0.012732**
(2) Punch	0.000004	2	0.000002	0.02528	0.975106
(3) % Cutting fluid	**0.001274**	**2**	**0.000637**	**8.389875**	**0.008777**
1 × 2	0.000112	1	0.000112	1.475657	0.255363
1 × 3	**0.000752**	**1**	**0.000752**	**9.905802**	**0.011788**
2 × 3	0.000142	1	0.000142	1.875345	0.204061
Error	0.000683	9	0.000076		
Total SS	0.003697	17			

(c) Var.: CONIC_{-}; $R^2 = 0.86934$; Adj: 0.7532 (análise7.sta) (1) 2-level factors, (2) 3-level factors, 18 runs – DV: CONIC_{-}; MS residual = 0.0001568

ANOVA/conical form	SS	d.f.	MS	*F*	*p*
(1) Angle	**0.002689**	**1**	**0.002689**	**17.14961**	**0.002517**
(2) Punch	**0.004233**	**2**	**0.002117**	**13.5**	**0.001953**
(3) % Cutting fluid	0.000233	2	0.000117	0.74409	0.502272
1 × 2	**0.0012**	**1**	**0.0012**	**7.65354**	**0.021878**
1 × 3	**0.000833**	**1**	**0.000833**	**5.31496**	**0.046584**
2 × 3	0.0002	1	0.0002	1.27559	0.287923
Error	0.001411	9	0.000157		
Total SS	0.0108	17			

(d) Var.: T2; $R^2 = 0.87136$; Adj: 0.75701 (análise7.sta) (1) 2-level factors, (2) 3-level factors, 18 runs – DV: T2; MS residual = 65.81327

ANOVA/temperature	SS	d.f.	MS	*F*	*p*
(1) Angle	**813.389**	1	**813.389**	**12.35904**	**0.006561**
(2) Punch	64	2	32	0.48622	0.630207
(3) % Cutting fluid	**2242.333**	2	**1121.167**	**17.03557**	**0.000871**
1 × 2	192	1	192	2.91734	0.121809
1 × 3	**645.333**	1	**645.333**	**9.80552**	**0.012095**
2 × 3	55.125	1	55.125	0.8376	0.38395
Error	592.319	9	65.813		
Total SS	4604.5	17			

approached the nominal diameter of 10.0 mm. Still it was observed that in all tests, punching tools with angle and lubrication/cooling with concentration of 75% Hislip, presented the smallest diameter variations with the mean values of 9.98 mm (independent of the tool geometric configuration—Punch tool I to III).

4.3. *Influence on hole conical form*

Through Fig. 5 it is possible to observe that, in agreement with the ANOVA, the punching tool angle affect the conical form of the holes in a significant way. However, it was observed that, holes made using tools with and without angle showed conical

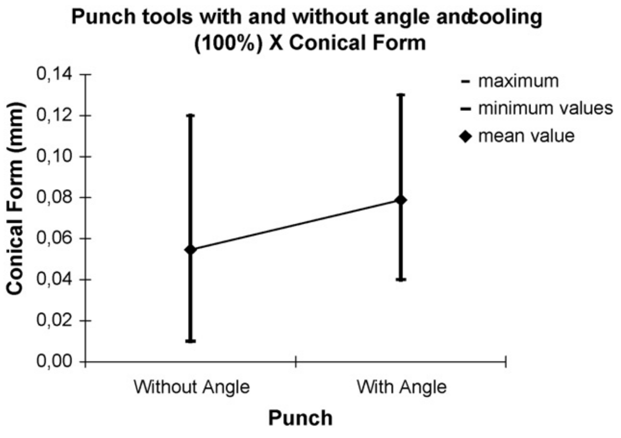

Fig. 5 – Conical form versus punch angle.

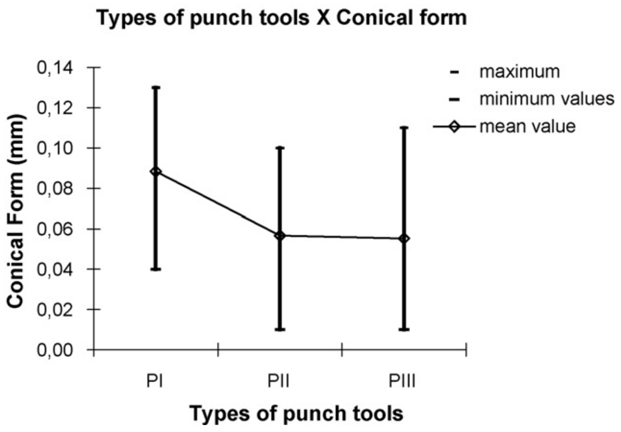

Fig. 6 – Conical form versus punch tool types.

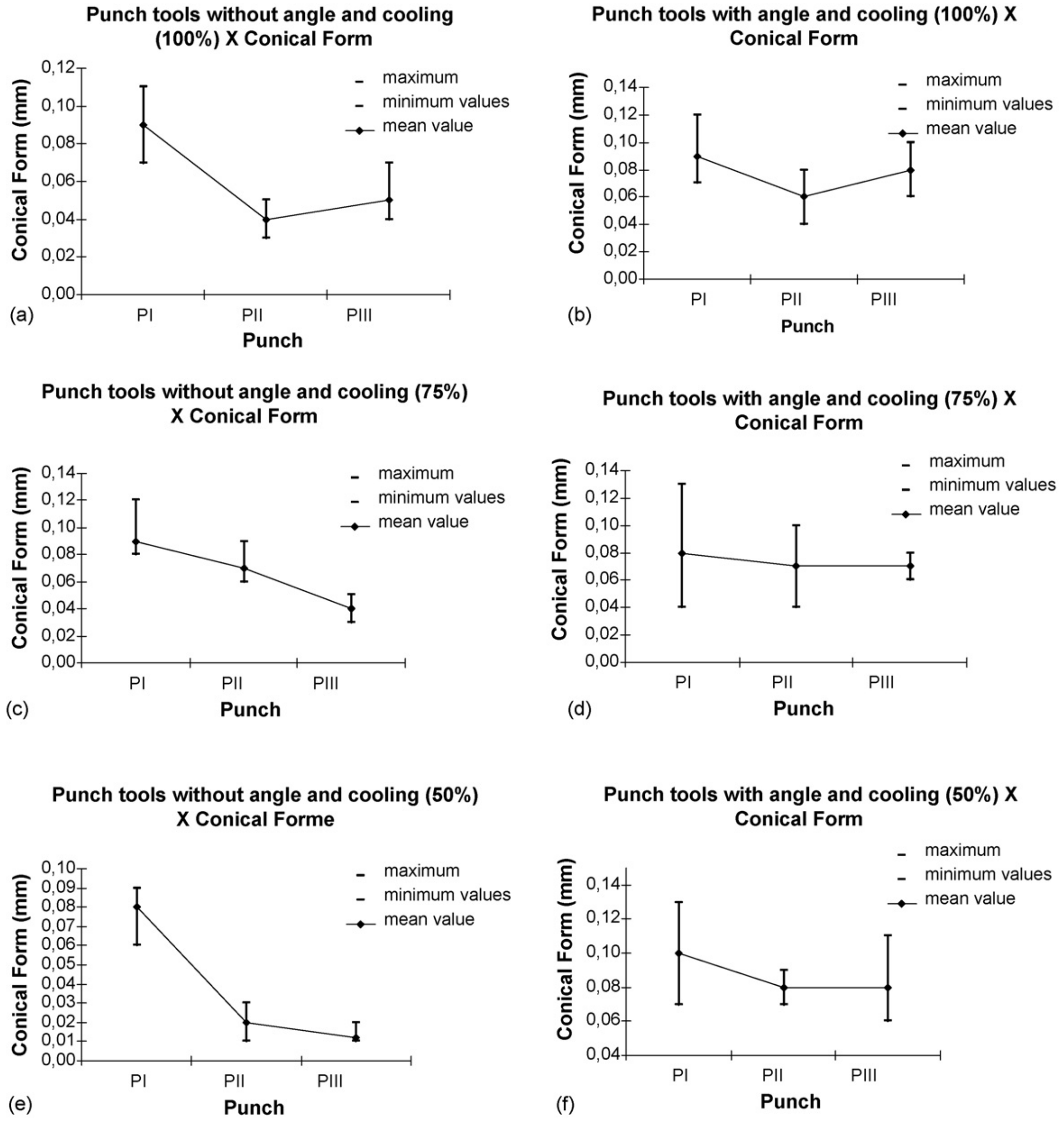

Fig. 7 – Conical form × punch tool types: (a) without angle and oil concentration of 100%; (b) with angle and oil concentration of 100%; (c) without angle and oil concentration of 75%; (d) with angle and oil concentration of 75%; (e) without angle and oil concentration of 50% and (f) with angle and oil concentration of 50%.

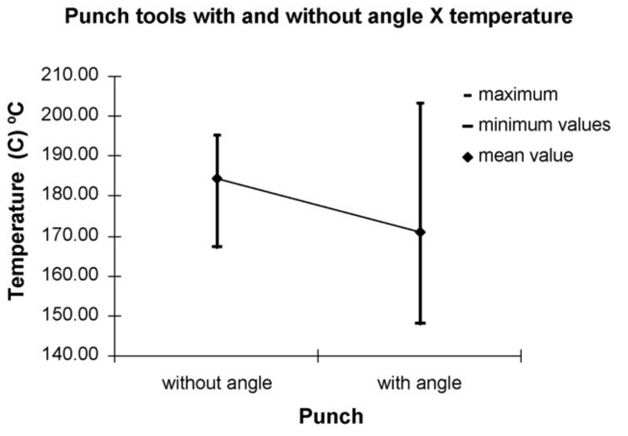

Fig. 8 – Temperature versus punch angle.

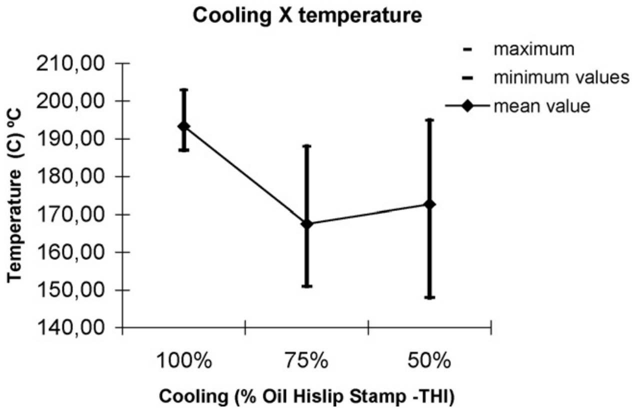

Fig. 9 – Temperature versus oil concentration (emulsion).

variation results of approximately ±0.05 mm which are quite close. Therefore, technically punched holes using tools with and without angle produced adequate results.

The hole conical form generated by tools, when cutting thick sheets, is a great problem due to the required clearance between the punching tool and the die. It could be noticed that in this combo process, of punching and broaching, the presented results were sufficient good for general applications. The biggest conical form variation found was about 0.13 mm. The clearance used for these punching tests was about 1.2 mm. In this combined process, the broaching tools segment reduces significantly the conic form of the holes until the broach gullets were completely filled with chips.

In Fig. 6, it is possible to see that tool types (I, II and III) affect the conical form of the holes. In other words, it is confirmed that the broaching teeth geometry has great influence to reduce the conical form of the holes. It is observed that in tool types II (progressive teeth in cutting and withdraw direction) and III (progressive teeth in cutting direction in two sections) the conical form mean value results are smaller than the conical form obtained with tool type I (progressive teeth in cutting direction). In tools II and III, the broaching process occurs twice, due to the double cutting made by broaching teeth in two sections. Through punching tool type II analysis it is possible to observe that there is an interruption between segments 1 and 2. Due to the cutting operation forces, there is an elastic recovering from metal sheets allowing a better cutting sequence and consequently, getting a reduction in hole conic form.

In Fig. 7, it could be seen the conical form versus punch tools types for all lubrication/cooling conditions, and the influence of the tool angle. It could be observed that, tool types II and III presented smallest hole conic form variation independent of the other variables. Tools with these geometries generate cuts in two stages, and the elastic material recovery could be reduced. Possible that is the reason for the better results. Although, tools without angle generated higher radial deformations, the observed results for tools types II and III were better even without angle.

Therefore, in agreement with ANOVA, the punching tool type affects the holes conical form. The punch angle has a little influence despite the correlation indicated by statistical evaluation. In terms of lubrication/cooling concentration, in the cutting emulsion, the smallest conical form result was obtained with oil concentration of 50% as showed by Fig. 7(e). In this experiment not only lubrication, but also, the cooling showed influence in the process, and this can be explained by the direct influence of the cooling in broaching (which helps to wash the chips away from the broaching gullets).

4.4. *Influence on tool temperatures*

The Fig. 8 shows the temperature versus punch angle. The data show that, the tool body temperature is affected by the tool angle presence. This is in coherence with the practice, since tools with angle affect punching processes and the heat generated during the process. It was also observed that, tool temperatures obtained with parallel punch are higher than the ones attained with tools with angles. Surprisingly, it was still verified that there was a smaller dispersion in temperature values for tools without angle when compared with values for tools with angle. This small dispersion could be influenced by important lubrication/cooling conditions during process, and it was not separated in Fig. 8.

As expected and indicated for ANOVA, broaching segments of tool types I, II or III, does not show influence in this process, as long as, tool types determines mainly the broaching characteristics. In this combined process, the temperature is more dependent of the punching than broaching.

The Fig. 9 shows the lubrication/cooling emulsion composition against tool temperatures. In this case, the smallest temperature was observed for punching tools lubricated/cooled for cutting fluid concentrations of 75 and 50% Hislip. This also indicates that, not only the lubrication, but also the cooling is important in this combo process. With more concentrations of water in this emulsion, cooling is more pronounced than lubrication.

The smallest temperature dispersion obtained with 75% Hislip concentration was in the range of ±18 °C. However, temperature differences between tests with oil concentrations of 100%, 75% or 50% is approximately 25 °C, which is of little importance in terms of cutting process. According to Trent (1984), the temperature that could affect the tools cutting edge life is in order of 600 °C. The temperatures found in those experiments were below 205 °C for any condition. Shaw

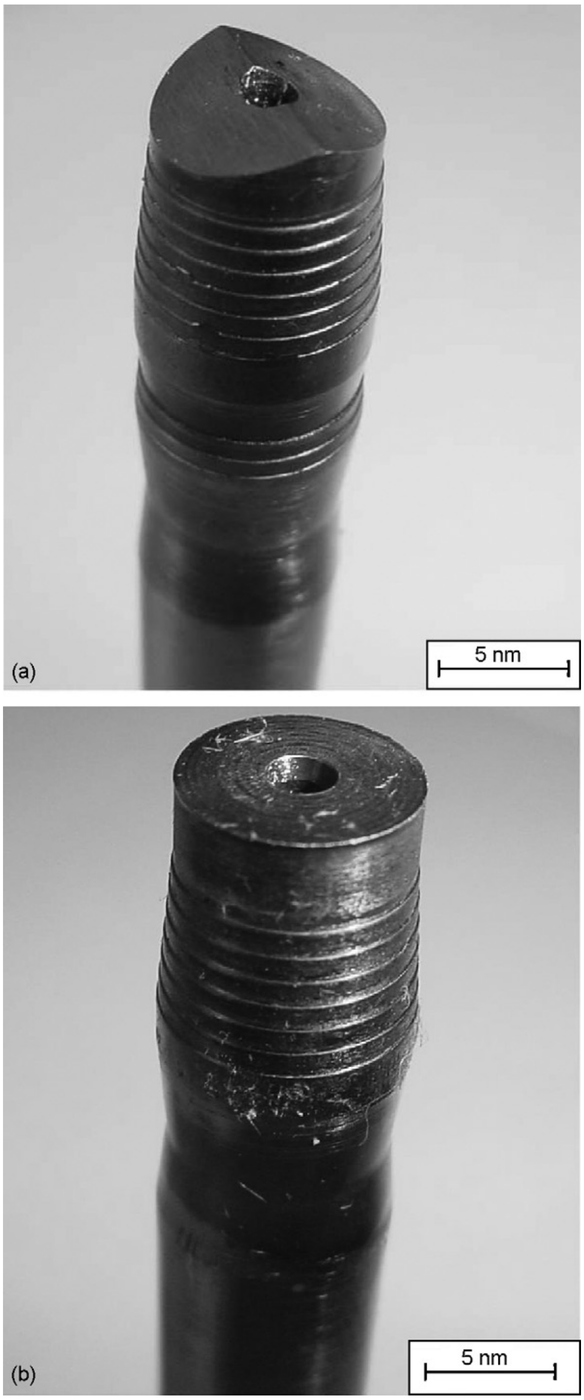

Fig. 10 – Visual tool degradation: (a) the regions with more shinning aspect in the teeth vicinity show a principle of abrasive wear (PIS50) and (b) the abrasive wear pattern is not visible indicating tool's higher wear resistance (PIIIC100).

(2005) also observed that, with low broaching speeds, lubrication characteristics were more necessary than cooling. In this present study, when concentration of 100% Hislip was used, relatively low temperatures and small results dispersion were observed (when compared with limiting temperatures of this process). Therefore, the tool temperature factor, that initially was considered to be more limiting for broaching (tooth degradation), does not seem to show great influence for this combined process.

In this work, the cutting tool degradation was evaluated according to the material adhesion tendencies and the teeth break through 100th punched holes. The evaluation was made with a magnifying glass of 10 times. This analysis shows that, PIIIC100 and PIC75 were the ones that presented smaller tool degradation and small material adherences. In Fig. 10(a) (PIS50) the regions with more shinning aspect in the teeth vicinity show signs of abrasive wear (Vb on the teeth sides). In Fig. 10(b) (PIIIC100) these regions are not visible indicating tool's higher wear resistance.

5. Conclusion

In this study, hole's final surface roughness, dimensional precision (hole diameter and conical form), as well as, tool temperatures and tool degradation, were evaluated and compared between tools with different geometries using different lubrication/ cooling concentrations of cutting fluids.

Regarding the hole surface roughness, it was shown that, broaching as a final operation of this combined process, defines the hole superficial quality, being also influenced by the tool angles. Tool type I with angle, progressive teeth in cutting direction, and 75–100% of Hislip concentration showed the smallest mean value and dispersion results for the surface roughness measurements.

In relation to hole dimensional precision, it was verified that, the combination of punching geometry and broaching strategies are responsible for hole dimensional results. For the conical form of the hole, it was observed that punching tools with angles does not affect hole geometries in a significant way. In this case, what determines the conical form, is the strategy for broaching (geometry of the broaching teeth). For this new combined process, not only lubrication but also the cutting fluid emulsion showed influence.

The temperature does not seem to exhibit great influence in this process and the punching tools PIC75 and PIIIC100 presented smaller tool degradation with small material adherences.

In short, the best combined punching and broaching tool was, tool type I (with progressive teeth in the cutting direction), with angle and concentrations of 75% of cutting fluid (25% water and 75% Hislip). The punching/ broaching tools of type II and III, presented the best hole conical form results due to the double cut of the broaching teeth.

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