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ASSESSMENT OF HOLE GEOMETRY IN AL-SI ALLOY USING HSS VK5 AND HARD METAL DRILLS WITH HIGH CUTTING SPEED

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Abstract. *With the development of new cutting tool materials and technologies it is possible to achieve cutting speeds today that would be inconceivable two decades ago. In the automotive industry, steel and cast iron have been gradually replaced by less dense materials which present also better machinability and cost-effectiveness. In this context, Al-Si alloys have found increased use in cylinder heads, gearboxes and other components. Holes are present in various diameters and depths and need to be machined in the shortest time possible within narrow dimensional tolerance ranges as well as shape (roundness, taper, roundness, etc.) and surface roughness parameters. In the present study VK5 HSS and hard metal drills were used for performing drilling operations on an automotive Al-Si alloy die-cast alloy with cutting speeds of 340m/min and 380m/min in order to analyze geometrical parameters of the drilled holes and tool wear. To this end, the evolution of hole diameter and surface roughness as a function of the number of machined parts was assessed. In both cases remained constant rotation in (8.000rpm and 10000rpm), forward speed (v_f) in (3168mm and min-3600mm/min) cutting speed (v_c) in (340m / min and 380m/min and). Comparing the evolution of the surface R_a, R_z and R_t, it is noted that the same remained stable over the testing*

Keywords: *Cutting speed, Error geometric shape, microscopy and scanning electron with EDS analyzer, hole geometry*

1. INTRODUCTION

Advanced manufacturing technology of high silicon aluminum alloys has been identified as one of the manufacturing processes most in need of new developments to obtain the required improvements for a new generation of vehicles. The advantage of using high speeds in machining aluminum alloys stems from the fact that their melting points fall well below the temperature at which modern tool materials experience thermal softening. The potential for increasing high speeds in machining aluminum alloys at speeds up to 5000 m/min is real and represents one order of magnitude increase over the current common practice in the automotive industry (M. Schultz, et al., 2000)

Authors studied the influence of cutting speed in a 35–200 m/min range and reported an increased flank surface temperature with the increasing cutting speed. However, the study of the influence of feed rate (0.05–0.4 mm/rev range) on flank surface temperature yielded the contradicting results. Chen reported a decreased flank surface temperature with the increasing feed rate.

whereas a more recent study by Weinert and Kempmann reported the contrary Rawat S, Attia H., 2009). The different workpiece thicknesses (2 and 17 mm) and the experimental arrangement utilised in both investigations (workpiece as the rotatory element) could have prevented the tool from reaching a steady state temperature (Weinert K, Kempmann C., 2004), thus explaining the difference in the reported results.

Aluminum alloys are largely employed in many industries because of their mechanical resistance, low density and easy machining in comparison to other metals. The addition of silicon to aluminum decreases its melting point and improves the abrasion resistance of the component. Hence, Al-Si alloys are used in the production of e.g. combustion engine components produced by pressure casting, which additionally require elevated fluidity and low solidification contraction. In drilling operations involving Al-Si alloys, cutting force and tool abrasion rate are low due to the good heat dissipation (Cotterell and Kelly, 2002), but difficulties may arise due to adherence of aluminum to the drill (Coldwell et al, 2004; Hu and Chou, 2007; Bhowmick and Alpas, 2008).

High-speed machining (HSM) is one of the most important manufacturing technologies for increasing productivity and decreasing costs. According to Kishawy and co-authors (Kishawy *et al*, 2005), the application of HSM to aluminum alloys is advantageous because their melting point (~ 650 °C) lies below temperatures at which cutting tools experience thermal softening. In addition, since the cutting temperature does not exceed the melting point of the aluminum alloy diffusion-wear, the most detrimental form of tool wear, does not take place (Trent and Wright, 2000).

Increasing cutting speed does, however, bear influence on other aspects of the drilling process since the overall quality of a hole obtained is determined by a synthesis of errors due to process dynamics and the thermal condition on the interface between component and cutting tool. Some of the mechanisms which induce process errors involve: deviation or abnormal drill rotation upon entrance, drill deflection due to force unbalances, general process failures, cuttings on drill edges, as well as thermal expansion of component and drill. Drill stiffness determines, largely, the errors induced due to dynamic mechanisms (Kalidas *et al*, 2001; Abele *et al*, 2010). Recently, for example, by comparing hydraulic-fit and interference-fit tool-holders applied to drilling Al-Si alloys, it was found that the higher stiffness of the interference-fit mounting provided better results with respect to hole diameter, roundness and surface roughness (Martins *et al*, 2012). Vibrations can also be attributed to the eccentricity generated by fixation insert failure leading to irregular drill radii. The existence of eccentricity produces changes in the cutting forces and also in the instantaneous force maximums depending on the cutting conditions, on the geometry of the cut and the nature of the eccentricity (Schoroeter *et al*, 2001).

Among the traditional machining processes, drilling is one of the most important metal cutting operations, consisting of 33% of all machining operations, and accounts for approximately 40% of all metal removal operations in the aerospace industry (Ertunc and Oysu, 2004). The temperature at the chip-tool interface has an important influence on the wear of the tool and the microstructure of the deformation region. According to Ozcelik (2006) temperatures increase with increasing hole depth for the same feed rate and spindle speed. Nouari (2003), in turn, shows that the maximum temperature in the drill cutting face is an increasing function of the cutting speed and feed speed.

It should be noted that the actual engineering surfaces are composed of shape, undulation and roughness and can be filtered in five stages. Deviations of the actual surface form can be assessed in terms of parameters such as circularity, cylindricity and surface roughness. The average surface roughness (R_a) can be expressed as the average deviation of a profile of your line or the average distance of a profile from its midline, on an average length (Oliveira, 2004; Martins, 2008).

The cutting speed, feed and depth of cut, respectively, V_c, f_n and a_p are the most important variables in this process. The cutting speed V_c is the instantaneous velocity of the reference point of the tool cutting edge, according to the direction and cutting direction. For processes with rotation, the cutting speed is calculated by Eq.1.

$$V_C = \frac{N * \pi * \emptyset}{1000} \qquad (1)$$

Where $\emptyset$ is the workpiece diameter (mm) and N corresponds to the number of revolutions per minute. The advance is the path of advancement at every turn (mm / rev) in each course or tool. The depth of cut a_p is the tool penetration depth or width in the play, measured in a direction perpendicular to the work plane (NBR6162 / 1989). In drilling with twist drills, the acting forces are related to the geometry of the drill and the cutting process conditions such as feed, cutting speed and rigidity of the assembly piece / machine tool (Arenas, 2003).

The combined friction at high working temperatures gradually damages the cutting edges of drills, thus, the lifetime of such tools is compromised (Jurko; Brychta, 2008; Sharman et al., 2008). Demanding that the drill be replaced or sharpened (Darvish *et al*., 2009). The catastrophic damage suffered by drills are usually generated by excessive force during machining (Huang, 2009).

In this study we evaluated the performance of VK5 High Speed Steel (HSS) and hard metal drills applied to machining automotive Al-Si alloys with cutting speeds of 340, 380 m/min.

2. EXPERIMETAL PROCEDURE

The materials used in the drilling experiments were Al-Si alloys currently used in the automotive industry for manufacturing cylinder heads. The test materials were used in the as-cast condition. An optical micrograph showing the typical microstructure is presented in Figure 1 and the chemical composition of the materials is presented in Table 1. The microstructure consists of an Al-rich α-phase in and eutectic, which can be either Al5Cu2Mg2Si6 or Al15(FeMn)3Si2 (Wain et al, 2005). The silicon content in the alloy means that the alloy has primary particles which promote the tool wear due to abrasion, when compared to other aluminum alloys.

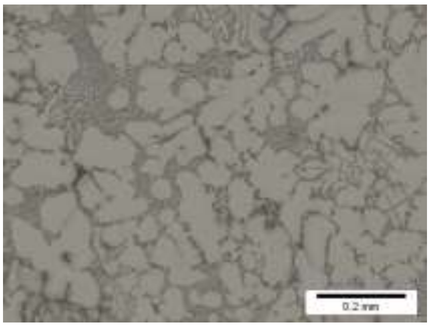


Fig. 1 – Microstructure of the Al-Si alloy used in the present study evidencing the light phase rich in aluminum and eutectic constituent.

Table 1: Chemical composition of the Al-Si alloy (all values in wt.%)

Element	Al	Si	Cu	Mg	Mn	Ti	Fe	Zn	Ni	Pb	Sn
Composition (%)	86.8	7.76	3.11	0.36	0.40	0.02	0.74	0.56	0.03	0.05	0.02

The cutting tools applied were uncoated based on WC+Co hard metals produced by sintering and VK5 HSS. The microstructure of the WC+Co material as observed by Scanning Electron Microscopy (SEM) is presented in Figure 2(a, c), which shows the characteristic morphology that consists of WC embedded in the cobalt binder phase. An Energy Dispersive X-ray Spectrometry (EDS) spectrum showing the main elements present in the cutting tool materials is presented in Figure 2(b, d). The elevated hardness of the carbide phase combined with the relatively softer and ductile binder material allow for excellent wear resistance.

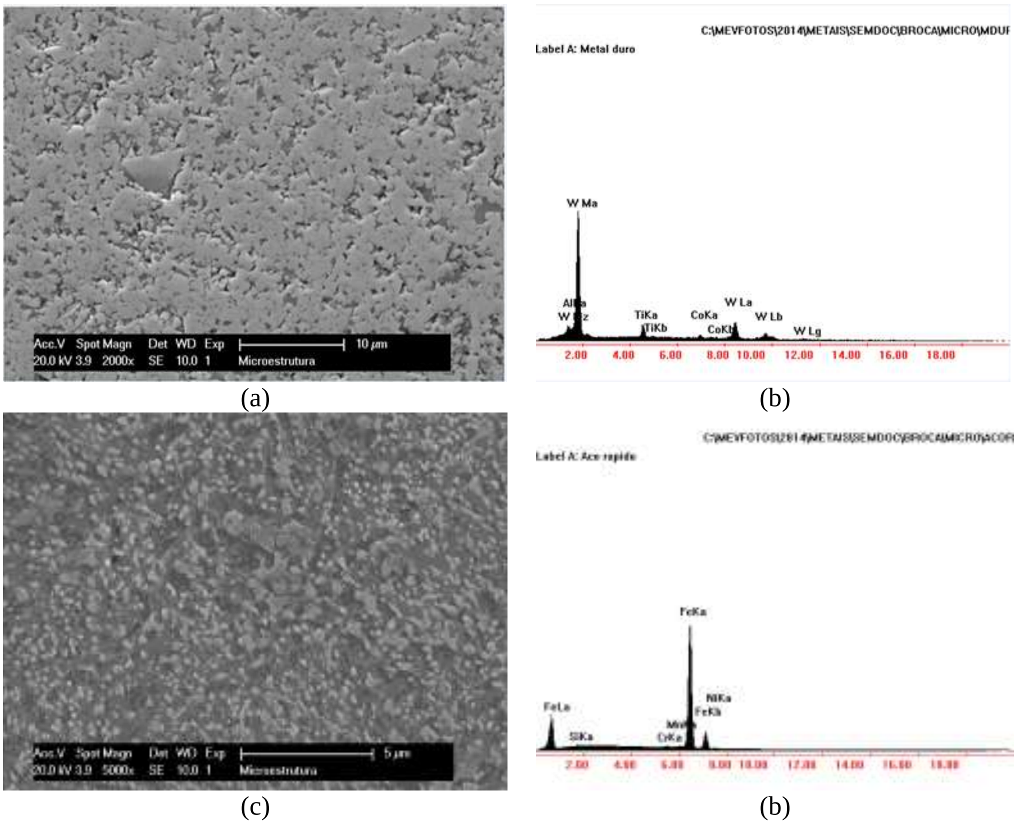


Fig. 2 – Microstructure of the hard metal and HSS VK5 cutting tool material (a, c) and chemical composition by EDS analysis (b, d).

The drills were applied with parallel rod, H7 allowance, first diameter tip angle of 145º (10º clearance angle), second diameter tip angle of 90º (8º clearance angle) and drill diameter of 12.150 mm (+0.025 +0.007). The machining experiments were performed after a pre-hole of 10.50 mm. The drills were housed in a HSK63 chuck (Figure 3) by applying a semi-automatic Speroni fixation device and some of the holes obtained after the final drilling stage are illustrated in Figure 3. The position of the holes on the Al-Si alloy cylinder heads is presented in Figure 4.

Fig. 3. – Housing of the hard metal end steel VK5drills

Fig. 4 – Holes A and B generated by the 12.150 mm drill.

The machining operations were performed on a Siemens 840D Hüller machining center equipped with numerical command. Cutting speed was set to 340, 380 and 430 mm/min with (8.000rpm-10000rpm-11300rpm), rotation and feed rate of 0.36 mm/revolution. A HOCUT B 205D cutting fluid with 6% to 8% concentration and 30 bar pressure cutting fluid was used and the drilled holes were 8 mm deep. Upon completion of the drilling operations, the pieces were cooled to room temperature and submitted to metrology analysis, for drill hard metal Specimens 1, 50, 100, 150, 200, 250, 300, 350, 400, 500, 1000, 1500, 2000, 3500, 5000, 6500, 8000, for drill steel VK5 1, 50, 100, 150, 200, 250, 300, 350, 400, 500, 1000, 1500, 2000, 3500 were taken in order to measure hole diameter and surface roughness parameters (R_a, R_z and R_t). The surface roughness parameters were determined a Taylor Hobson Form-Talysurf series equipment equipped with Gaussian coarseness filter, 0.8 mm cut-off and 4.8 mm length.

3. RESULTS AND DISCUSSION

The evolution of diameter measurements as a function of the number of machined parts is presented in Figure 5 For the first 4000 pieces, distribution of values is uniform with an average constant value of approximately 12.180 mm. However, after this point, dimensional values increase considerably because of the progressive degradation of the tool. This is in turn caused by the friction between drill and workpiece, which promotes detachment of small carbide particles from the cutting material during chip removal. After 11500 pieces, the diameter values achieved the maximum allowed according to design specifications.

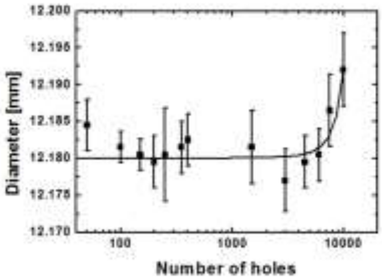


Fig 5 – Evolution of diameter as a function of the number of machined parts

Figure 6 shows the evolution of the diameter of the holes from parts 1 to 3100 which were obtained with the VK5 HSS with cutting speeds of 340m/min and 380 m/min. The behavior is significantly different from that observed in

Figure 5. One may perhaps explain this result by the nature of the wear that occurs on the drill side and also in the adhesion of the material to drill. For this limited number of holes, the adhesion is physical and not chemical which makes easier the withdrawal of the material throughout the machining process.

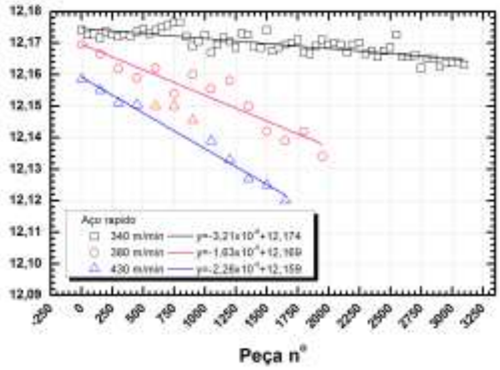
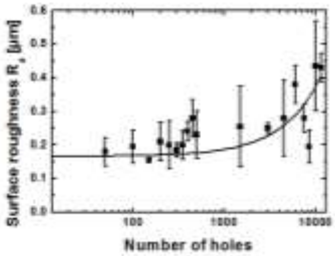
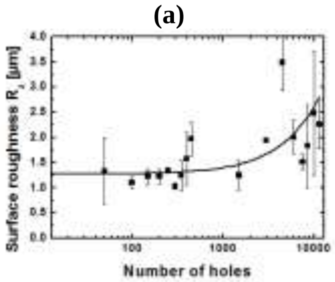


Fig 6 – Hole diameter for both cutting speeds in relation to the number of parts.

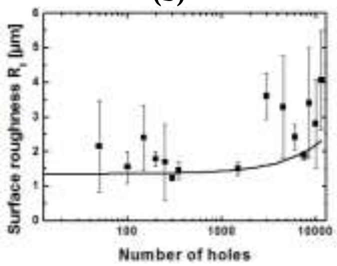
The variation of surface roughness in terms of parameters Ra, Rt and Rz are presented in Figure 7(a), (b) and (c), respectively An increase in the surface roughness of the holes drilled in the Al-Si alloy can be identified in all cases after approximately 2000 holes. In a previous investigation, Martins and co-workers (Martins et al, 2009) showed the evolution of surface texture in Al-Si alloy machined with hard metal tools with and without TiCN coatings and observed variations of up to 4 μm. In that study, higher values of surface roughness were observed on the coated drill due to adhesion. Presently, the increase in roughness appears also to be connected to tool wear. It is worth noticing that the results presented in Figure 8 show a progressive increase in roughness from parts 1 to 500 followed by a reduction (for R_a and R_z parameters). This effect is caused by the removal of the adhered Al-Si from the drills, which was performed in order to assess flank wear. The cleaned drills were then continuously used until 11500 holes.



(a)



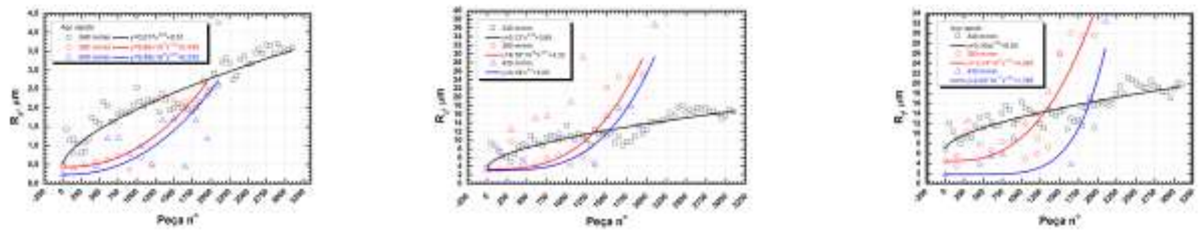
(b)



(c)

Fig 7(a, b e c) - Evolution of surface roughness as a function of the number of drilled parts: (a) R_a (b) R_z and (c) R_t.

The evolution of surface parameters Ra, R_z and R_t as a function of the number of drilled parts for cutting speeds of 340 m/min and 380 m/min is presented in Figure 8. The cutting speed bears significant influence on surface roughness of the holes with a larger average roughness for 340 m/min. The average and dispersion values of R_z and R_t analyzed surface for both types showed different behavior speed between the number of holes 1500 for both cutting speeds. From the hole 1750, the average roughness R_z and R_t parameters increased for both cutting speeds, which is caused by tool wear.



(a) (b) (c)

Fig 8(a, b e c) - Evolution of surface roughness as a function of the number of drilled parts: (a) R_a (b) R_z and (c) R_t.

4. CONCLUSIONS

Dimensional analysis revealed constant diameter values up to 4000 holes. After approximately 8000 operations, values shifted towards the maximum pre-determined design limit, because of increased tool wear. Surface parameters (R_a, R_z and R_t) obtained similar mean values. For the 380 m/min cutting speed, the tests were only performed up to 2100 parts because from that point on hole diameter achieved the minimum admissible value. At high speeds the diameters of comparing values were worse at low speed, this phenomenon occurs due to the increased friction of the edge of the tool to the material machined.

5. REFERENCES

ARENAS MIRANDA, G. W., Uma contribuição ao processo de furação sem fluido de corte com broca de metal duro revestida com TiAlN Tese de Doutorado, Departamento de Engenharia Mecânica, UNICAMP, Campinas, Brasil, 2003

Coldwell HL, Dewes RC, Aspinwall DK, Renevier NM, Teer DG. The use of soft/lubricating coatings when dry drilling BS L168 aluminium alloy, Surface and Coatings Technology, 2004, 177-118, p. 716-726.

Cotterell MG, Kelly JF. Minimal lubrication machining of aluminum alloys, Journal of Materials Processing Technology, 2002, 120, p. 327-334.

DARVISH, K.; SHAFIEIAN, M.; REHMAN, S. The effect of tip geometry on the mechanical performance of unused and reprocessed orthopaedic drill bits. Journal of Engineering in Medicine, v. 223, n. 5, p. 625-635, 2009.

ERTUNC, H. M.; OYSU, C. Drill wear monitoring using cutting force signals Mechatronics; v. 14, pp 533-548, 2004.

Harris SG, Doyle ED, Vlasveld AC, Audy J, Quick D. A study of the wear mechanisms of Ti1-xAlxN and Ti1-x-yAlxCryN coated high-speed steel twist drills under dry machining conditions, Wear, 2004, p.723-734.

HUANG, B. W. Model of vibration in drilling into fibre-reinforced composite materials. Journal of Engineering Manufacture, v. 223, n. 9, p. 1107-1114, 2009.

JURKO, J.; BRYCHTA, J. Analysis of Thermodynamical Phenomenas of Stainless Steels by Drilling. Transactions of the VŠB - Technical University of Ostrava, Mechanical Series, n. 8, p. 1-6, 2008.

Kalidas S, De Vor RE, Kapoor SG. Experimental investigation of the effect of drill coatings on hole quality under dry and wet drilling conditions, Surface and Coating Technology, 2001, 148, p.117-128.

Kishway HA, Dumitrescu M, Ng EG, Elbestawi MA. Effect of coolant strategy on tool performance, chip morphology and surface quality during high-speed machining of A356 aluminum alloy, International Journal of Machine Tools & Manufacture, 2005, 45, p. 219-227.

Martins P, Carneiro JRG, Brito P, Vilela L, Lourenço M. Influence of Hydraulic and Interference-fit Tool Holders on Tool Wear and Hole Quality in the Drilling of Al-Si Cylinder Heads, Mechanical Engineering Research, 2012, 2, p. 29-35.

Martins P, Maia L, Costa L, Lourenço M, Carneiro, JRG, Landre, J. Comparação entre a furação utilizando broca de metal duro com canal polido sem revestimento e com revestimento TiCN em liga de alumínio-sílicio, 6º CONGRESSO BRASILEIRO DE ENGENHARIA DE FABRICAÇÃO, 2011 – Caxias do Sul – RS – Brasil.

OLIVEIRA C. J., Avaliação da Influência de Sistemas de Filtragem Aplicados a Topografia de Superfície em Usinagens Dissertação de Mestrado PUC Minas, 2004.

OZCELIK, B.; BAGCI, E. "Investigation of the effect of drilling condition on the twist drill temperature during stepby-step and continuous dry drilling" Materials and Design, n 27, pp 446-454, 2006.

Schroeter, RB, Weingaertner WL, Macedo, SEM. Analyze of forces on the milling. Máquinas e Metais, 2001, p. 130-139.

Trent EM, Wright PK. Metal Cutting 4th Ed. Boston: Butterworth-Heinemann, 2000, p. 254-258.

M. Schultz, et al., Limits for the application of long protruding tools regarding the process stability and safety, Proceedings of the Second International Seminar on Improving Machine Tool Performance, La Baule, France, 2000.

Rawat S, Attia H. Wear mechanisms and tool life management of WC-Co drills during dry high speed drilling of woven carbon fibre composites. Wear 2009;267(5–8):1022–30.

Weinert K, Kempmann C. Cutting temperatures and their effects on the machining behaviour in drilling reinforced plastic composites. Adv Eng Mater 2004;6(8):684–9 (p. 612).

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