MONITORING OF THE DRILLING PROCESS IN DUPLEX STAINLESS STEEL

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Abstract. *Through a strain gage drilling cutting forces dynamometer, SAF 2205 duplex stainless steels samples were machined with different cutting parameters (feed rate and cutting speed), coatings (without coating and TiAlN) and sharpness (conical and special cross-sharpened) for HSS twist drills. The results were sufficient to correlate the drilling cutting forces and the other involved parameters with the quality of the obtained holes. The better quality of the holes was obtained with TiAlN coated drill with cross-sharpened point, although the sharpness has not been the major influent parameter.*

Keywords: *drilling, HSS twist drill, duplex stainless steel, cutting, and dynamometer*

1. Introduction

Hole producing is one of the most used processes in the manufacturing industry [Halewi, 1995 and Diniz, 2001], and in this process, the tool has to withstand extreme environments that include high temperatures, high frictional forces and large mechanical loads [Kalidas, 2001]. This requires the tool to have high hot hardness, high refractivity and low friction coefficient.

The duplex stainless steel (DSS) presents different cutting conditions when compared with another stainless steel and there are not many researches about the machining of this material, that is used for many applications as described on the next topic. The duplex stainless steel SAF 2205 is supplied by many producers and distributors in numerous products forms and is the most widely used duplex stainless steel (Sedriks, 1996) and for this, it was choose for this work.

The TiAlN coatings are designed for the machining of abrasive materials such as high silicon contents aluminum alloys and for high thermal stress conditions. This last was used for select this coating during this work, because even using cutting fluid in abundance the tool can be reach at high temperatures, mainly as the hole depth in increased and reach closer to the 4x diameter, as studied by Bordinassi, 2003.

This work concentrates its attention in hole machining on duplex stainless steel SAF 2205 workpiece processed by drilling with high speed steel twist drills. A spoke-wheel type spindle dynamometer was used to monitor the torque and the thrust forces during the drilling. As process variable to be evaluated by dynamometric measurements it was took the drill point sharpening geometry and coatings, as well as cutting speed and feed rate.

2. The duplex stainless steel (DSS)

The duplex stainless steel is characterized by a mixed structure, in approximately equal parts of austenite (γ) and ferrite (δ). This structure is obtained through a controlled chemical analysis and balanced heat treatment (Charles, 1995). The balanced chemical composition based on high contents of Cr and Mo, improve the intergranular and pitting corrosion respectively.

The stainless steel, to be considered a duplex, need to has a value of pitting resistance equivalent (PRE) greater than 20 (Nilsson, 1992).

The main utilization areas for duplex stainless steel are:

- Gas and oil industry: heat changers and pipes for production of gas and oil;
- Chemical industry: pressure vessels, pipes and tanks for the processing and transport of chemical products;

- Petroleum industry: pressure vessels, tanks and pipes in the processing of clorets products;
- Paper and pumps industry: rotors, fans, shafts and rollers, where high fatigue corrosion resistance must be used;
- Due to his high PRE, in human implants.

Nowadays, 30% of the projects that need of stainless steel with better resistance corrosion than a one AISI 316, use duplex stainless steel.

The main characteristics of duplex stainless steel are:

- High mechanical resistance;
- High pitting and crevice resistance;
- High fatigue and erosion resistance;
- Low thermal expansion and greater thermal conductibility than the austenitic stainless steels;
- Good machinability and welding;
- High energy absorption;
- Magnetic comportament;

2.1 - The machining of duplex stainless steel

The stainless steels in general present different behaviors in the machining, when compared with other steels. It is characterized mainly for:

- High work hardening rates, that induce mechanical modifications and heterogeneous behavior in the generated surfaces, and take to the unstable chip formation and vibrations (Saoubi et al, 1999);
- Low thermal conductivity (Korkut et al, 2004). The conduction of heat corresponds for the approximately ¼ of the value found for cutting of a common steel. (Neves et al, 2003);
- High fracture resistance, resulting in high temperatures, difficult chip breaking and consequently low superficial quality (Jang et al, 1996);
- BUE formation, and in a different way from the conventional steels, it's can appear in higher speed cuttings, due its high fracture resistance, and high work hardening rates;
- High wear of the tools, due to the high cutting forces that the tool is submitted, and frequently small material pieces are removed from the tool, due to the high adhesion in the rake surface;

The main problems found in the machining of stainless steel due to the difficulty cutting are: tool wear, poor superficial finish, long chips and low speed cutting (Machado et al, 2003).

The duplex stainless steels have yield strengths typically about twice that of the non-nitrogen alloyed austenitic grades, and their initial work hardening rate is at least comparable to that of the common austenitic grades. The chip formed when machining DSS is strong and abrasive to the tooling, and especially so for more highly alloyed duplex grades (International Molybdenum Association, 2001). So, because of this characteristics and considering that the machinability of the material frequently is compared with its PRE (Paro et al, 2001), the difficulties in the cutting of duplex stainless steel tend to increase.

Maybe the main difference in machining DSS is that DSS are relative easier to machine with high-speed steel tools than with cemented carbide tools compared to austenitic stainless steel with similar alloy content [Avesta Polarit, 2002]. The machinability can be illustrated by a machinability index, as illustrated in Figure 1. This index, which increases with improved machinability, is based on a combination of test data from several different machining operations. The figure provides a good description of machinability in relation to 1.4436 (ASTM 316). Note however, that the machinability index does not describe the relative difficult between high-speed steel and carbide tools.

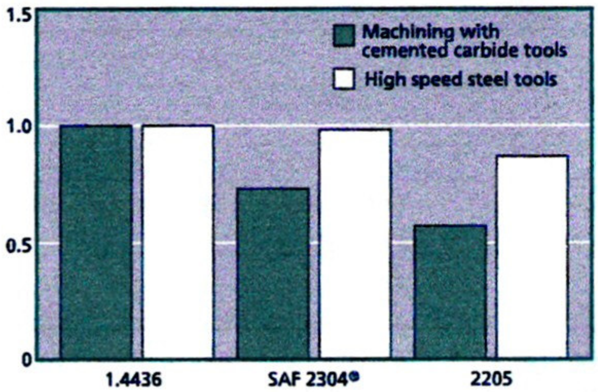

Figure 1 – Machinability index for duplex and some other stainless steels [Avesta Polarit, 2002].

Guidelines for twist drilling duplex stainless steels with HSS drills are [International Molybdenum Association, 2001]:

- Drill geometry ⇒ point angle 130°; self-centering drill point geometry is recommended; web thinning for large diameter drills is recommended;
- Coolant ⇒ 10% emulsion with ample flow to tool point; for depth greater than 2x diameter, remove chips by periodic withdrawal with flooding of coolant in hole;
- Increased speeds ⇒ Coating permits 10% increase; through drill coolant permits 10-20% increase.
- For drill diameter 5mm and SAF 2205 ⇒ cutting speed: 10-12 m/min; feed rate 0,1 mm/rev;

The selected parameters for the tests, described in the next topic, were based on this data and from information from the drills Manufacturer's.

3. Methods and materials

Workpiece: Duplex Stainless Steel SAF 2205, cold rolled, ∅1"
Hardness: 250 HB
Mainly Chemical composition (% in mass):

Cr	Ni	Mo	N	C	Mn	Si	P	S	Fe
22,21	5,40	3,15	0,18	0,02	0,76	0,45	0,02	0,05	rest.

Tools:
1) ϕ6mm, high speed steel twist drill, conical sharpened DIN 338;
2) ϕ6mm, high speed steel twist drill, cross sharpened (special for stainless steels) and based on NAS 907;
3) ϕ6mm, high speed steel twist drill, conical sharpened DIN 338, TiAlN coated;
4) ϕ6mm, high speed steel twist drill, sharpened (special for stainless steels) and based on NAS 907, TiAlN coated;

Drilling parameters:

Letter	Vc [m/min]	f [mm/v]
A	9	0,05
B	12	0,05
C	9	0,1
D	12	0,1
E	10,5	0,075

Center Machine: - Romi Discovery 560

Cutting Fluid: - All the holes were drilled with 5% emulsion of mineral oil Rocol Ultracut 250 in abundancy

Dynamometer: - Strain gage drilling dynamometer

Acquisition system: - A hardware (System ST5000) and a software (AQUISI Mi–V0.26) developed by Spectra Tecnologia

Coordinate measurement machine: - Mitutoyo B231

Surface roughness tester: - Mitutoyo Surftest SJ201

The specimens were prepared to be fixed in the dynamometer. After the fixation, a center hole was made and to follow, the drill with the selected cutting parameters began the drilling. All the holes had length of 18mm, not characterizing in this way deep drilling.

In the beginning of the experiments it was tried to use higher cutting speeds (18m/min), but it was observed that with this cutting depth, the wear caused in the main edges of the drill during the execution of one hole, was already enough to disable it, and in this sense, smaller cutting parameters was selected according showed above.

4. Experimental results and discussion

The Figure 2, shows the different measured diameters for each cutting parameters group. The results showed that hole diameters obtained with the HSS conical drill, are the bigger values for all the cutting parameters group. Considering the mean value of all holes drilled, it can be noted that the biggest value was found for the HSS conical, the second biggest value for HSS cross-sharpened. The third for HSS TiAlN and the better results was obtained with last one drills (HSS TiAlN Cross sharpened). Also, can be noted that the coating drills presents the better values for the diameter of holes.

The Figure 3, presents the effects of the mean cutting forces under the diameter. The results shows similar values, as the last one figure presented, and that for this topic the better feed rate and cutting speed were the biggest. The Figure 3 also presents that the feed rate has a greater influence than the cutting speed under the diameter.

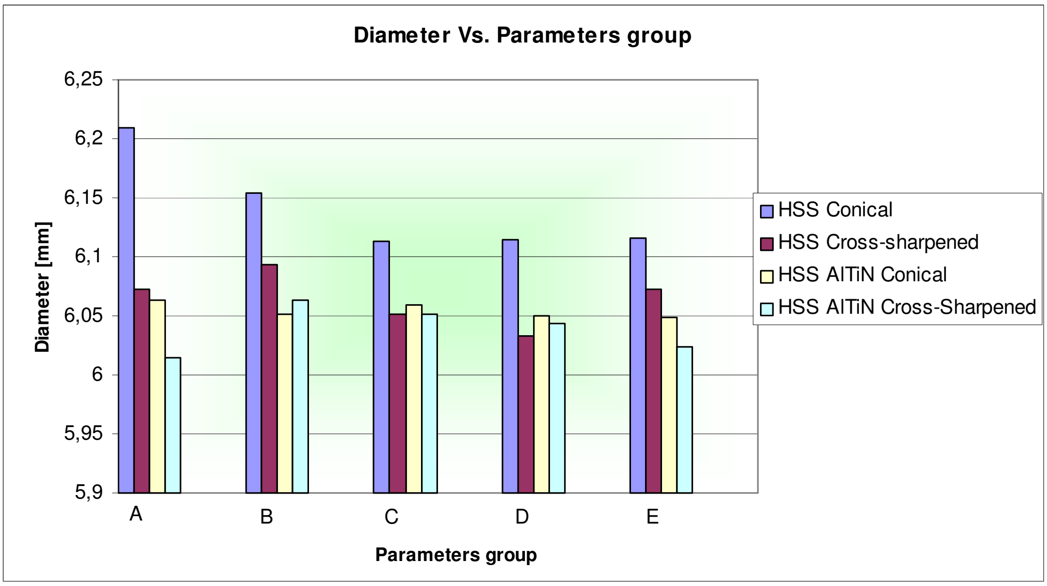

Figure 2 – Holes diameter Vs. Cutting parameters group

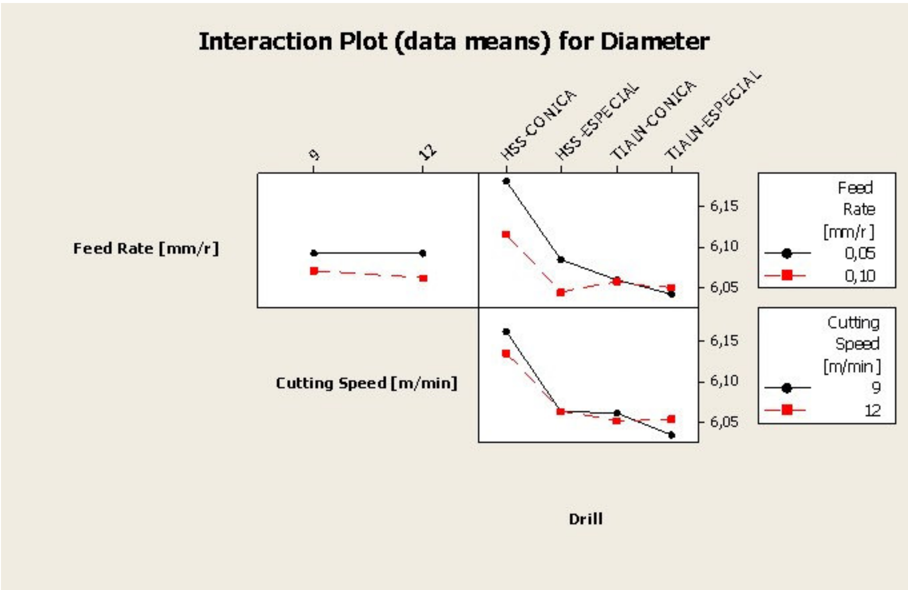

Figure 3 – Effects of the mean cutting factors under the diameter

The Figure 4, presents the effects of the mean cutting forces under the roughness. As can bee noted, the increase of the cutting speed and the decrease of the feed rate, make holes with smaller roughness. The HSS special cross-sharpened drill presents the biggest roughness, when compared with the others.

The Figure 2, Figure 3 and Figure 4, shows that the coating drills presents better results for the hole diameter and it's roughness, than the drills without coating, for the cutting parameters used.

The Figure 5 and Figure 6, shows the effects of the mean cutting factors under the thrust force and torque. The feed rate, as expect, presented great influence and the cutting speed the smaller, and again the HSS twist drill conical presented the poor results for the drilling, with bigger forces. The smaller cutting forces can be justified for fact that coatings improve the friction between the tool/workpiece, and in this way, the chip movement in the drilling is facilitate due to it's chip evacuation characteristics. The results found in this work, was similar of Kalidas, 2001 during the cast aluminum drilling, with respect as the drilling diameter, because the TiAlN coating has a significant effect on average hole radius, decreasing the hole size. The character of these coatings is providing a thermal shield to the drill while discouraging more heat to be absorbed by the workpiece.

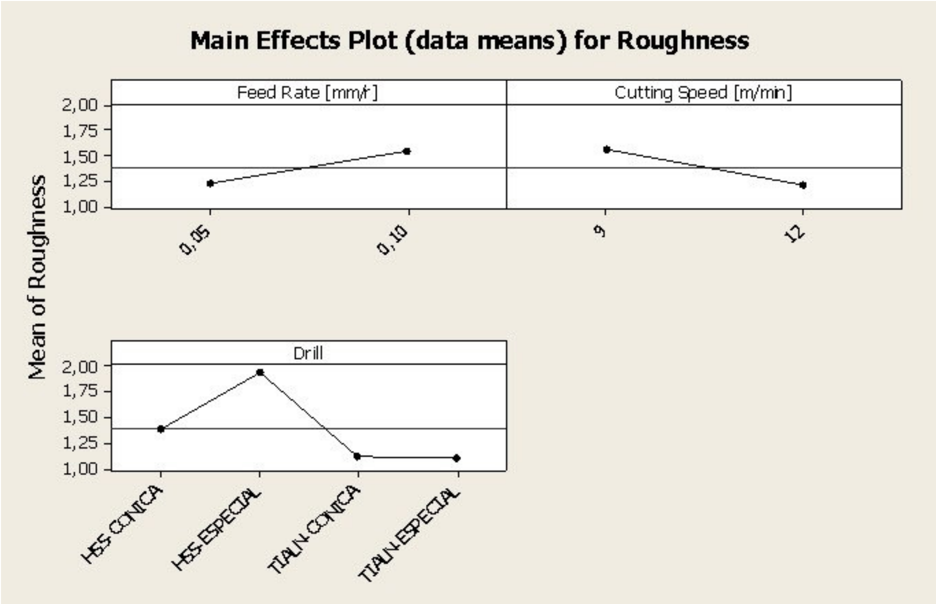

Figure 4 - Effects of the mean cutting factors under the roughness

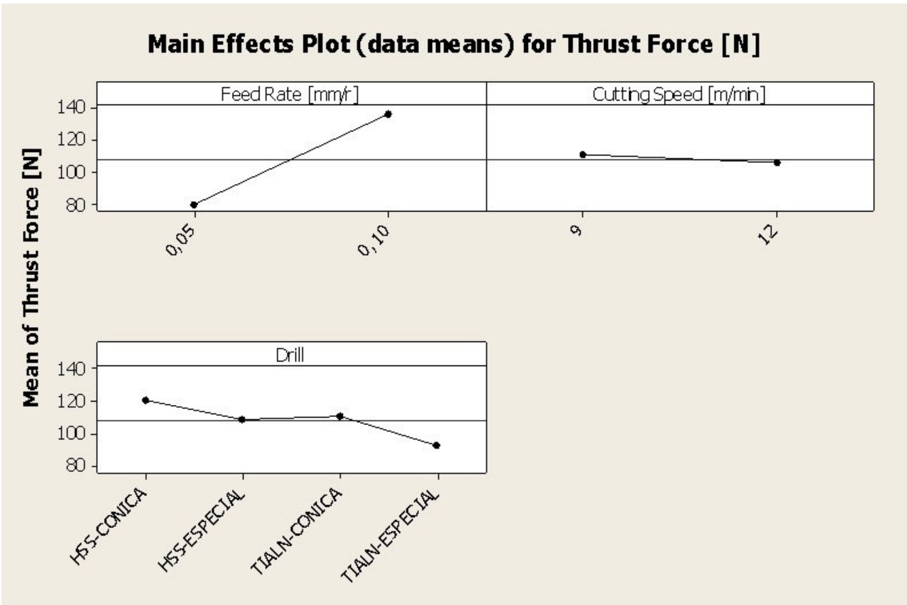

Figure 5 - Effects of the mean cutting factors under the Thrust force

A correlation between the cutting forces and it's consequences (diameter and it's roughness) was try to be made, but the Figure 7 and Figure 8 showed that it was not possible. The same figures show that in general, as commented before, the coating drills presented smaller cutting forces, but even for the same cutting forces, a difference in the quality of hole (diameter and roughness) was found. Another observations is that, in some cases, the biggest values for cutting forces, provide better quality of the hole.

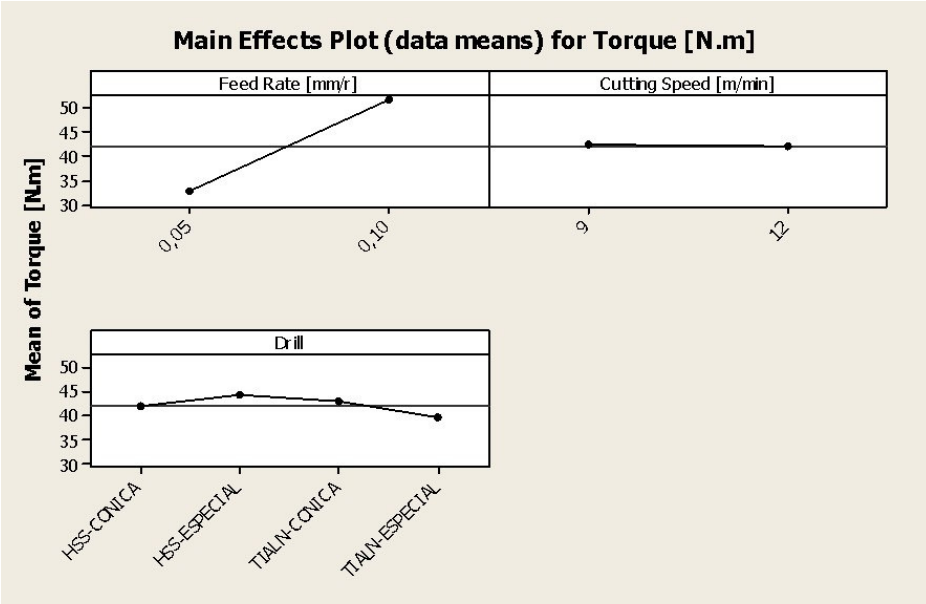

Figure 6 - Effects of the mean cutting factors under the Torque

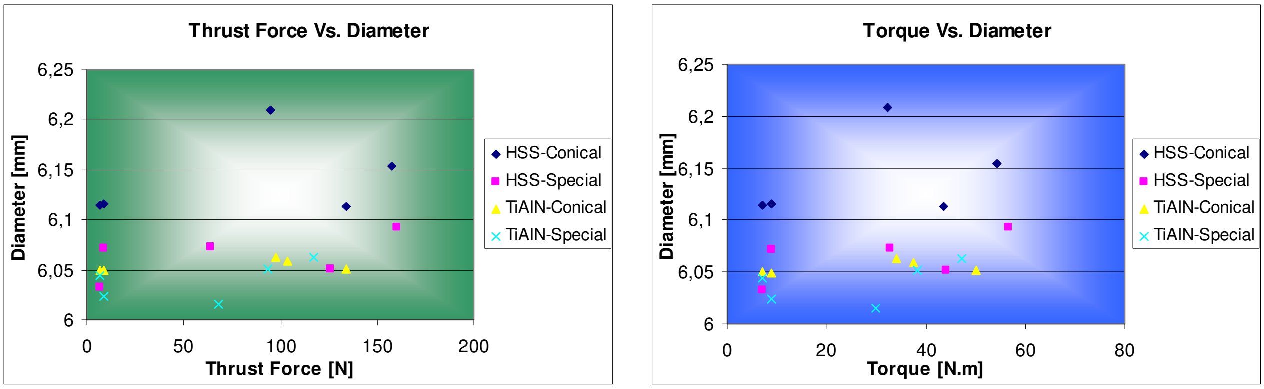

Figure 7 – Relation Between cutting forces and diameter

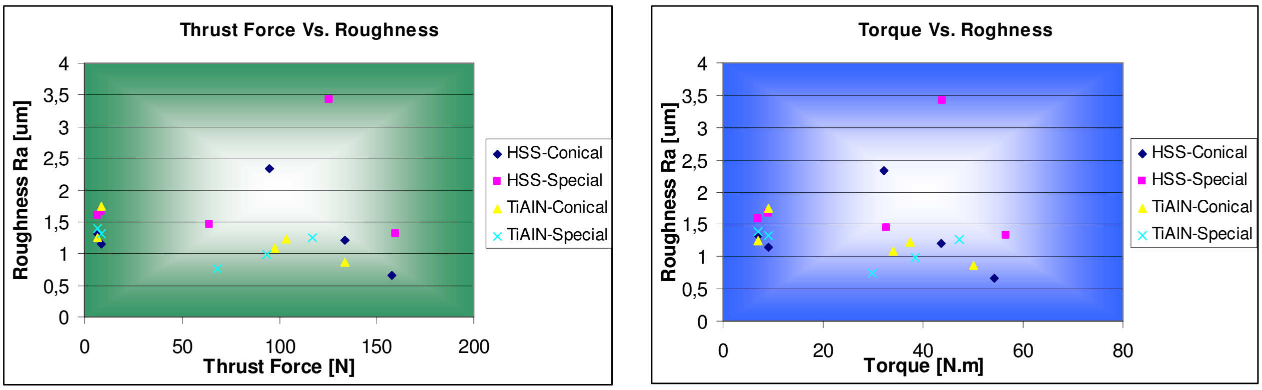

Figure 8 – Relation between cutting forces and roughness

5. Conclusions

The following conclusion were possible to be established:

- ✓ The cutting forces present a correlation when compared with the cutting parameters. The feed rate is the most important factor for the drilling;
- ✓ It was not possible to make correlation of cutting forces and the quality of the holes;
- ✓ Bigger feed rates and cutting speeds are better (considering the values used in this work) for the smaller hole's diameter;
- ✓ Smaller feed rates and bigger cutting speeds are better (considering the values used in this work) for the smaller hole's roughness;
- ✓ The special sharpened drills presented some improvements in the cutting forces and hole quality when the drills without coating were used, but for the coated drills it's effects were smaller;
- ✓ The coatings presents better results on the holes when compared against the drill without coatings (smaller cutting forces and better quality of the holes);

6. Acknowledgements

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