AN ASSESSMENT OF THE MACHINABILITY ON TURNING OF A DIN 9SMn28 STEEL WITH DIFFERENT FREE CUTTING ADDITIVES

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Abstract. In this work, a machinability assessment study was carried out in a DIN 9SMn28 resulfurized steel with different free cutting additives. Three variants of the steel were tested: the plain form of the DIN 9SMn28, with bismuth addition and with bismuth and boron additions. The tests were performed with HSS and carbide tools on a turning machine, and the Taylor equation was obtained for all cases. The results have shown that the boron-added steel brought about the best tool lives at all cutting conditions for both tools, followed by the bismuth- added in most of the analyzed conditions.

Keywords. *machinability on turning, HSS and carbide tools, free cutting additive ,DIN 9SMn28 steel, Taylor equation.*

1. Introduction

The massive technological development that took place last century made production processes faster and more efficient in different branches of the industry. In order to keep up with the development achieved in machines and tools, the improvement of raw materials became necessary – a classic example to be mentioned here is the development of special steels aimed at making the manufacturing of components easier. These steels improve the processes of welding (through the characteristic known as weldability), hot and cold forming, powder metallurgy and/or machining, being common applications those in which the combination of different properties is needed.

In the specific case of the development of special steels with the objective of obtaining a better performance in machining operations, the resultant materials are called free cutting steels and the characteristic that summarizes this improvement is called machinability.

Free cutting steels are among the most employed special steels in industry, which reflects the importance of the machining processes. According to Walker (2000), it is hard to find any product that does not require, directly or indirectly, the use of any machining operation in its manufacturing. These processes turn into chip roughly 10% of the world production of metals, according to Trent (1984).

The material machinability is influenced by several characteristics related to the material itself as much as to the machining process and cutting tools applied in the operation. As far as the material is concerned, the main factors that affect the machinability are its chemical composition and microstructure, where adjustments in chemical composition are the most applied means to obtain a free cutting steel.

Certain elements (called free cutting additives), when added to steel, bring about an improvement in the machinability by different mechanisms. The most used free cutting additives are sulfur (which forms manganese sulfide non-metallic inclusions), phosphorus and lead, due to their efficiency in improving the steel machinability as well as their low cost.

As previously mentioned, sulfur promotes a rising in the machinability through the formation of manganese sulfide inclusions that, besides reducing cutting forces by the decrease of the material shear strength, causes an increase in tool life through the generation of an MnS layer on the tool face, which also reduces the cutting forces and consequently the machining temperature (Trent and Wright, 2000; Jian et. al, 1996; Jha and Sharma, 1990). As a negative side effect, the addition of sulfur deteriorates the material's mechanical properties; especially shear strength, but also hot workability and corrosion resistance. Additionally, due to the generation of MnS inclusions, sulfur brings along anisotropy to the mechanically-worked steels, according to several authors (Somekawa et. al., 2001; Tsunekage et. al., 2000).

Lead is the most used free cutting additive after sulfur, promoting machinability due to the generation of metallic inclusions that favor chip breakage, the lubricant effect that it creates on the tool face and the physical protection of the potentially worn surfaces (Mills and Redford, 1983; Jah and Sharma, 1990), with minimal modifications in material properties. However, lead alloying has been less frequent in the last few years due to its high toxicity – environmental agencies are imposing some restrictions through strict laws on lead use and even manufactures are getting conscious of the hazardous nature of this element.

Due to the negative aspects of lead employment as a free cutting additive, there is a need to seek an alternative to this element. The most used element for lead substitution is bismuth. Very close to the lead in the periodic table, bismuth owns a low fusion temperature, besides some characteristics that differ it from other metals: it expands during solidification and presents the lowest thermal conductivity in solid state among all metals (Ojebuoboh, 1992).

Somekawa et. al. (2001), evaluating lead and bismuth-added steels' machinability, verified a similar behavior among the analyzed steels, showing a clear rising on machinability compared to carbon-steels without free cutting elements. Concerning lead, it has been reported that this element has a small effect on steel machinability at high cutting speeds. This phenomenon is due to the rising temperature caused by the small contact area between the chip and the workpiece, which can accelerate the wear of carbide tools.

Bismuth effect on free cutting steels is similar to lead's; however, having the advantage of being non-toxic, not affecting the properties of the steel (since lower proportions of bismuth, about one third will confer the same gain if compared to lead) and providing better surface finishing to the manufactured components.

Reh et. al. (1979) found the machinability of a boron-added DIN 9SMn28 resulfurized steel to be better than the machinability of the plain resulfurized steel, when turning with HSS tool. The observed effects were higher tool lives, lower cutting pressure and improved surface finish. Annovazzi (1983) found a boron-added steel to be better than the same steel with lead addition. The addition of boron forms B_2O_3.MnO inclusions that improve machinability acting as a lubricant, improving tool lives and surface finish and reducing cutting forces.

This work evaluates the effect of different alloy additions on the machinability of free cutting steels. The benefits of bismuth and boron are evaluated on cylindrical external turning operations with carbide and HSS tools. A comparison between the ordinary resulfurized steel and the other steels is done through the Taylor equation and parameters such as the surface finish of the machined workpieces.

2. Experimental procedure

In this work, the machining behavior of low carbon resulfurized steels with free cutting additives was analyzed. The additives studied were bismuth and boron, and the chemical composition of the resulting steels are shown in Table (1). The reference steel (A), as B and C steels, are produced by Gerdau Aços Finos Piratini (Rio Grande do Sul state, southern Brazil) and their trading names are CORFAC® S300 and CORFAC® CB300.

Table 1. Chemical composition of the tested steels.

Steel	C	Si	Mn	P	S	Cr	Ni	Mo	V	Cu	Pb	Bi	B
A[1]	0.074	<0.01	1.18	0.080	0.320	0.11	0.09	0.02	0.002	0.15	-	<0.01	-
B[2]	0.078	0.01	1.18	0.079	0.297	0.08	0.18	0.03	0.002	0.11	-	0.10	-
C[3]	0.040	0.01	1.12	0.081	0.293	0.06	0.09	0.02	0.003	0.12	-	0.05	*

[1]CORFAC® S300; [2]CORFAC® CB300; [3]CORFAC® CB300. *Not available.

Long duration machinability tests were conducted on a cylindrical external turning process with HSS and carbide tools, whose operational parameters are shown in Table (2).

Tests were carried out on cylindrical workpieces with original diameters of 69.85 mm (rolled bars). Some preparation steps were performed on the workpieces prior to the turning tests: center hole drilling, removal of the oxidized layer down to the 68 mm final diameter and a groove at the end of the cutting length to facilitate tool clearance. The machined length of the workpieces was defined as a function of the cutting speed in such a way that each pass occurred at a 1 minute interval, after which the tool was withdrawn for wear measurements. This procedure was then repeated until the tool life criterion was reached (Table (3)).

Each turning test was carried out at 3 different cutting speeds (Table (4)), defined according to the slope of the Taylor equation (observed in pre-tests). For each cutting speed, 3 repetitions were conducted with each cutting tool. Due to their superior tool life, it became impracticable to machine the steels B and C (alloyed with bismuth and bismuth and boron, respectively) at the same cutting speeds applied to the other test (steel A). For this reason, the cutting speed ranges for these steels were higher than the ones applied to the reference steel, so much with carbide as with HSS tools (for steel C).

Table 2. Applied machining parameters to the turning tests

Tool material	Carbide P15	HSS ABNT M2
Coating	TiN/Al_2O_3	None
Tool geometry	a_0 = 6°; c = 93°; l = -6°; g_0 = -6°*; r_e = 0.4mm	a_0 = 8°; c = 75°; l = 0°; g_0 = 25°; e_r = 90°
Chip-breaker	Integral, g = 15°*	None
Feed (mm/rev)	0.15	0.1
Cut depth (mm)	0.8	1.0
Cutting fluid	Dry	Dry

*effective g = 9°

Table 3. Tool life criteria adopted.

Tool material	Tool life criteria
Carbide	VB_{Max} = 0.3mm
HSS	Catastrophic failure

Table 4. Cutting speeds applied.

Steel	Tool	Vc (m/min)
A	HSS	132, 140, 150
B	HSS	132, 140, 150
C	HSS	140, 160, 180
A	Carbide	355, 400, 450
B	Carbide	355, 450, 560
C	Carbide	560, 600, 630

3. Results

Figure 1 shows the maximum tool flank wear evolution for steels A, B and C machined with carbide tools. It is clear that the tendency shown in all repetitions indicates a constant growth of VB_{Max} with cutting time, except for steel C, where there is a more accentuated dispersion of results, besides a less regular increase at the lowest speed. When machining with HSS tool, a prominent dispersion of VB_{Max} could be observed with cutting time, motivating the adoption of catastrophic failure as the tool life criterion. Tool life time values obtained with high-speed steel and carbide tools are shown in Tables (5) and (6).

Table 5. Tool life results obtained when machining with carbide tool for cutting speeds shown in Table (4).

Steel	Vc1*	Vc2*	Vc3*
A	18.05±1.16 min	10.36±2.70 min	6.59±0.36 min
B	17.13±0.85 min	10.80±0.70 min	9.14±0.14 min
C	24.67±6.43 min	16.67±2.52 min	11.00±1.00 min

* Vc1 = lowest cutting speed, Vc2 = intermediate cutting speed, Vc3 = highest cutting speed

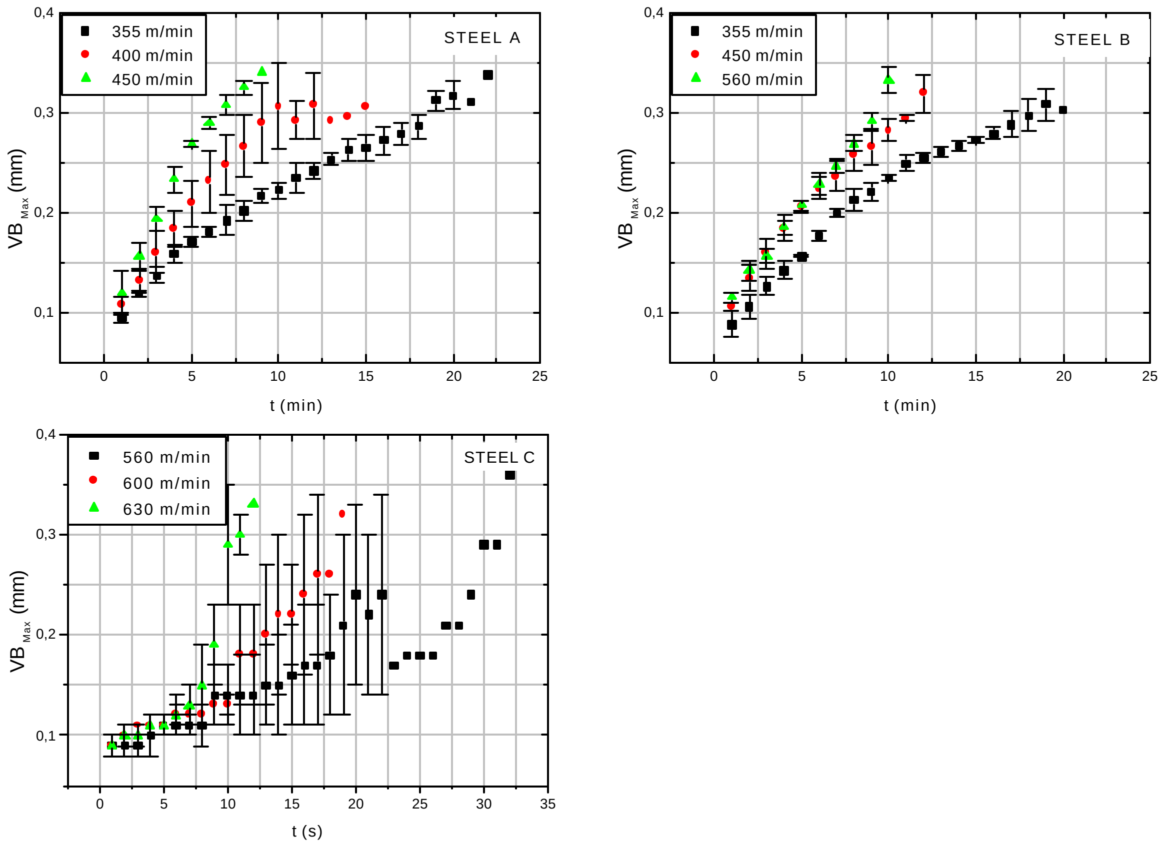

Figure 1. Maximum flank wear evolution as a function of cutting time when using carbide tool for steels A to C.

Table 6. Tool life results obtained when machining with high-speed steel tool for cutting speeds shown in Table (4).

Steel	Vc1*	Vc2*	Vc3*
A	17.33±4.51 min	10.33±2.52 min	7.00±0.82 min
B	36.30±3.76 min	23.00±6.24 min	12.75±4.11 min
C	47.00±7.81 min	25.33±5.51 min	4.67±1.53 min

* Vc1 = lowest cutting speed, Vc2 = intermediate cutting speed, Vc3 = highest cutting speed

From the results of tool life time, Taylor equations were fitted to the experimental data for all three steels. Figure 2 shows Taylor equations obtained when machining with carbide tools. The boron-added steel showed an enhanced behavior in machining along the entire speed range, followed by steel B (bismuth-added) for speeds above 350 m/min.

Figure 3 depicts Taylor equations obtained when turning with high-speed steel tools. It could be observed an increased machinability for steel C (boron-added) comparing to the other steels in the whole range of speeds tested. In addition, the machinability of steel B was superior to that shown by the reference steel (A) for the full range of speeds.

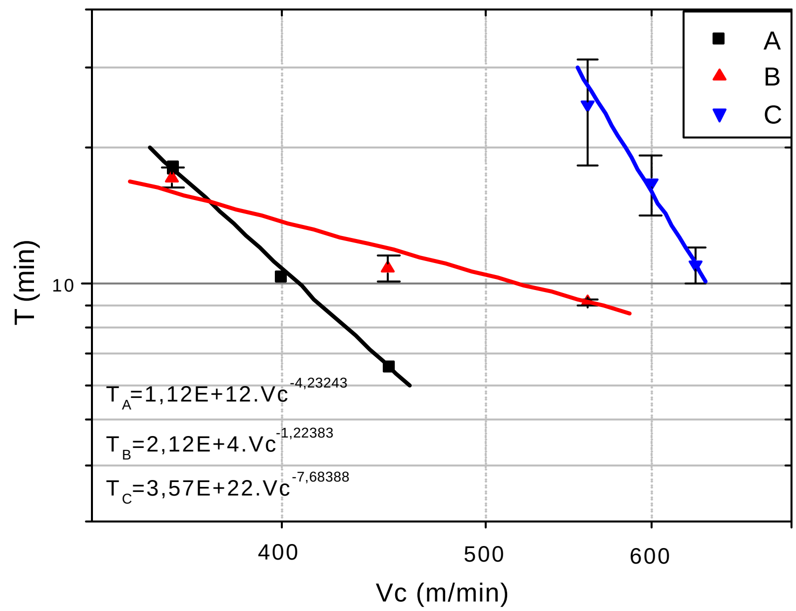

Figure 2. Taylor curves for tests carried out with carbide tools.

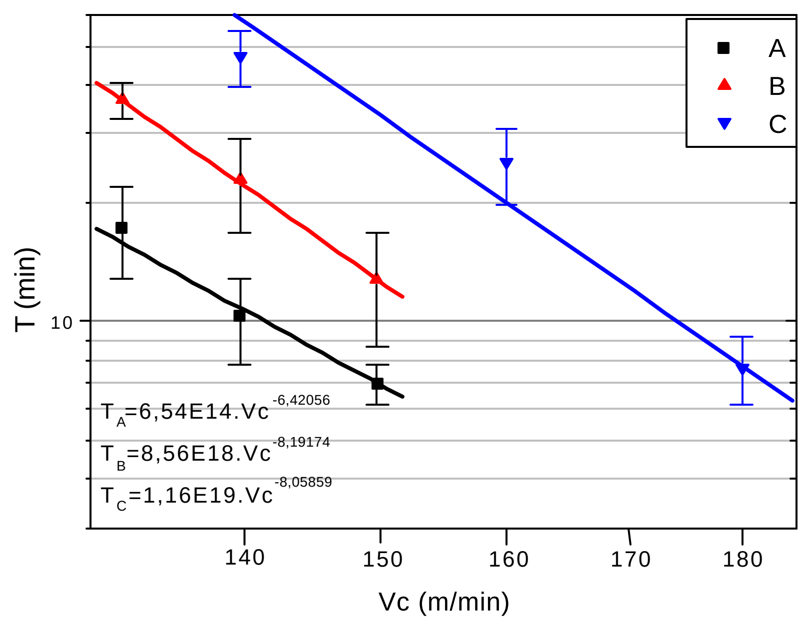

Figure 3. Taylor curves for tests carried out with HSS tools.

4. Conclusions

From literature review as well as an analysis of the experimental results, it can be concluded that:

- At the cutting conditions studied with high-speed steel tools, the resulfurized steel treated with bismuth and boron presented the highest machinability, followed by the bismuth-treated steel and the plain resulfurized steel. The high machinability of steel C was obtained due to the combination of lower carbon content and the addition of boron.
- The boron-treated steel was able to be machined at the highest cutting speed tested in this investigation. Actually, the machining tests of the boron steel with carbide tool had to be carried out at a higher cutting speed band.

- A prominent difference between Taylor equation slopes of both steels was observed when turning with carbide tools. There is a weaker influence of cutting speed on the tool life in the bismuth-added steel compared to the other steels. The highest slope happened to be in the case of the boron-added steel, which explains the high tool lives observed at lower cutting speeds.
- Even though it presents the longest tool life time at all conditions analyzed, boron-treated steels also exhibits the highest dispersion of results when compared to the other steels. New tests are underway to evaluate the repeatability of the results.
- Bismuth-added steel showed improved machinability when compared to the plain form of the same steel. Its non-toxic feature makes bismuth a very suitable alternative to lead substitution in free cutting steels.
- Both free cutting steels B and C showed higher tool lives when compared with the plain resulfurized steel (A).

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