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# MACHINING OPTIMIZATION ANALYSIS FOR THE PRODUCTION OF C110 STEEL SPECIMEN

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*Abstract. The C110 steel is used in oil industry applications where it is exposed to a highly corrosive aqueous environment. In order to verify the resistance of this steel to corrosion, tests are carried out, such as the corrosion under voltage, regulated by the standard NACE TM0177. The test specimens for this test are manufactured by a series of operation procedures, initializing by turning operation. Subsequently, as the specimen must have a surface roughness $R_a$ maximum of 0,250 μm, it is necessary to do a grinding process. The main aim of this paper is to analyses a turning proposes in order to eliminate the need of a grinding process. For this, it was analyzed the behavior of roughness parameters, such as $R_a$, $R_q$, and $R_z$ surface machined in test specimens using carbide and cermet tools with the same cutting speed varying the feed rate (0.05; 0.10; 0.15) mm/rev.* Results showed that it was not possible to reach the roughness limit of 0.025 μm using the parameters of this work. The best value founded was of 0.0277 μm, using hard metal and *feed rate* of 0.05 mm/rev value relatively close to. Further studies should be necessary to verify the feasibility of eliminating gridding finishing by just using turning operation.

*Keywords: Turning operation, C110 Steel, roughness, gridding.*

## 1. INTRODUCTION

A subgroup of DIN 8580 cites the term "separate" being the means of characterizing processes with chip removal, with defined geometry tool. For Ferraresi (1970), it is understood as machining those operation that, when conferring to the part the shape, or the dimensions or the finish, or a combination any of these three items, produce chip. Chips can be defined as a piece of material of the piece, removed by the tool, characterized by irregular geometric shape.

The branch of the machining technique marks the basic principle of the industry. It works the raw material for industrial production, in contrast to the practice and science of the application of this product. (WITTE, 1998).

The Cr-Mo grade C110 steel, it is largely used in the oil industry by its good corrosion resistance. This steel is well described in the classification of the API SPECIFICATION 5CT, *"Specification for casing and tubing"*. When compared with carbon steel, it presents excellent toughness, corrosion resistance and creep behavior, as well as low coefficient of thermal expansion (SAMPAIO, 2013).

In order to know the properties of the materials used in the engineering, it is commonly used test specimens for destructive tests, such as the stress *test x deformation*, these tests are elaborated with several machining processes, with some parameters or norms during the machining so that the manufacturing process of the test body does not interfere with the properties of the material to be analyzed.

Standard TM0177 (2016) regulates the test specimen that addresses the tensile strength test on combined action of tensile stress and corrosion in aqueous media containing hydrogen sulphide ($H_2S$). The test consists of applying a load on

the test piece through a permanent device where it is exposed to solution saturated with the H₂S gas for 720 hours. This exposure to hydrogen sulphide generates a process known as hydrogen embrittlement that can affect several metals, most notably in high strength steels. The main effects include the reduction of ductility, cracking or even rupture.

Section 8.2.6 of TM0177 (2016) of test specimen establishes a maximum value for surface roughness $R_a$ of 0,250 μm Actually, it is a very low value to be obtained in terms of turning operation, so, other finish procedures are normally taken to obtain this roughness characteristics, just as mechanical grinding or by electrolytic polishing.

## 2. EXPERIMENTAL PROCEDURES

Figure 1 demonstrates an example of the specimen TM0177 (2016) that was performed in this work.



Figure 1. Example of a TM0177 (2016) normalized specimen
Source: own author

The fabrication and finishing of this spicemen was performed at a CNC Romi lathe, model GL240, numerical control Fanuc, of serial number: 016.011271.464. This machine is powered in 220V and 60Hz three phase motor of 20cv of power and maximum rotation of the Shaft of 6000RPM.

Figure 2 demonstrates the standard specimen dimensions according to NACE TM0177. According to item 8.2.5 of the NACE TM0177 standard, the sum of the last two finishing passes of the test piece must take an amount of not more than 0.05 mm of material, so the finishing was done by two passes with $a_p = 0.025\ mm$ and other parameters according as shown in Tab. 1.



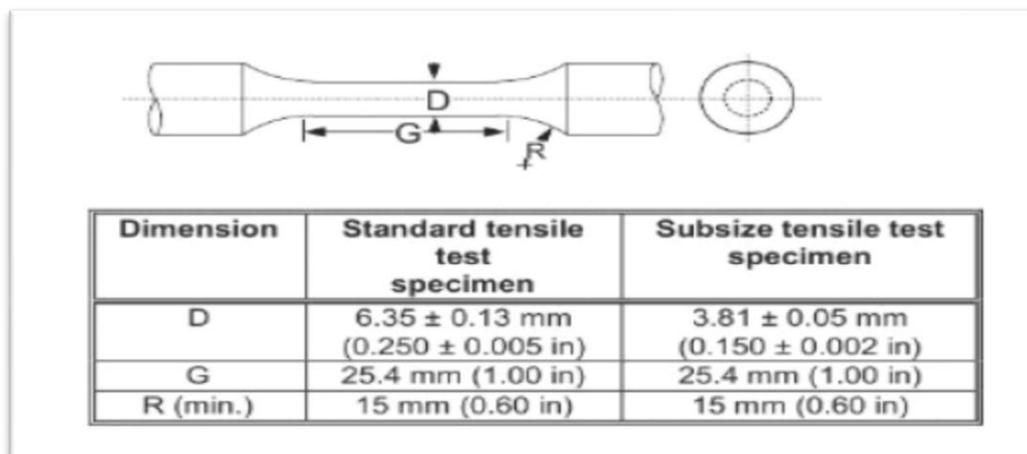| Dimension | Standard tensile test specimen | Subsize tensile test specimen |
|---|---|---|
| D | 6.35 ± 0.13 mm (0.250 ± 0.005 in) | 3.81 ± 0.05 mm (0.150 ± 0.002 in) |
| G | 25.4 mm (1.00 in) | 25.4 mm (1.00 in) |
| R (min.) | 15 mm (0.60 in) | 15 mm (0.60 in) |

Figure 2. Specimen specifications by standard NACE TM0177
Source: NACE TM0177

Table 1. Parameters used in last two passes

| Cutting speed (m/min) | Feed rate (mim/rev) |
|---|---|
|  | 0,05 |
| 115 | 0,10 |
|  | 0,15 |

Inserts used in the present work have ISO DCMT 070208 geometry, with 55 ° angle and 0.8 mm tip radius. The inserts were mounted perpendicularly due to the geometry of the specimen. Only one edge of each carbide and cermet insert

was used. It should be noted that the inserts have similar chip breaks, the hard metal insert has a chip break of the LB type and the cermet insert has a chip break of the FB type. Each insert was submitted to three specimens at the specified feed rates (Tab. 1), resulting in 18 finishes Table 2 shows details of this step contenting pieces identification (1 to 18) and the respective insert and *feed rate used.* Figure. 3 shows the inserts used in this work. Roughness measurements, $R_a$, $R_q$ and $R_z$, was performed using a rugosimeter Mitutoyo brand, model SJ 210 and serial number: 104.611.005.



Figure 3. Example of inserts and their positions in turning operation
Source: own author

Table 2. Pieces identification

| Insert | Feed rate (mm/rev.) | | |
|---|---|---|---|
| | **0,05** | **0,10** | **0,15** |
| **Hard metal** | Pc 01 | Pc 07 | Pc 13 |
| | Pc 02 | Pc 08 | Pc 14 |
| | Pc 03 | Pc 09 | Pc 15 |
| **Cermet** | Pc 04 | Pc 10 | Pc 16 |
| | Pc 05 | Pc11 | Pc 17 |
| | Pc 06 | Pc 12 | Pc 18 |

Two chemical analysis tests were performed to verify the composition of alloy of specimen used in this work and it is shown in Tab. 3.

Table 3. Chemical analysis of steel *C-110* in %.

| Test | Mn | Mo | Cr | Ni | P | S | C |
|---|---|---|---|---|---|---|---|
| # 1 | 0,43 | 0,84 | 0,92 | 0,02 | 0,009 | 0,002 | 0,27 |
| # 2 | 0,44 | 0,81 | 0,97 | 0,03 | 0,008 | 0,001 | 0,28 |

## 3. RESULTS AND DISCUSSION

Tables 4, 5 and 6 show the values measured from the rugosimeter for the parameter Ra, for each test body 4 random points on the surface were measured, then the mean and the standard deviation were calculated using Microsoft Excel software.

Table 4. Roughness ($R_a$) results for *feed rate* of 0.05 mm/rev.

| Material | Piece | Measurement 1 (µm) | Measurement 2 (µm) | Measurement 3 (µm) | Measurement 4 (µm) | Average per piece | Total average | Standard deviation |
|---|---|---|---|---|---|---|---|---|
| **Hard metal** | 01 | 0,277 | 0,285 | 0,288 | 0,287 | **0,284** | **0,294** | **0,016** |
| | 02 | 0,288 | 0,287 | 0,283 | 0,319 | **0,294** | | |
| | 03 | 0,293 | 0,291 | 0,298 | 0,332 | **0,304** | | |
| **Cermet** | 04 | 0,384 | 0,696 | 0,674 | 0,581 | **0,584** | **0,504** | **0,141** |
| | 05 | 0,654 | 0,673 | 0,346 | 0,392 | **0,516** | | |

| | 06 | 0,471 | 0,371 | 0,355 | 0,450 | **0,412** | | |

Table 5. Roughness ($R_a$) results for *feed rate* of 0.10 mm/rev

| Material | Piece | Measurement 1 (µm) | Measurement 2 (µm) | Measurement 3 (µm) | Measurement 4 (µm) | Average per piece | Total average | Standard deviation |
|---|---|---|---|---|---|---|---|---|
| **Hard metal** | 07 | 0,544 | 0,417 | 0,573 | 0,577 | **0,528** | **0,496** | **0,055** |
| | 08 | 0,510 | 0,472 | 0,523 | 0,520 | **0,506** | | |
| | 09 | 0,476 | 0,436 | 0,488 | 0,419 | **0,455** | | |
| **Cermet** | 10 | 0,605 | 0,604 | 0,655 | 0,586 | **0,613** | **0,607** | **0,028** |
| | 11 | 0,612 | 0,614 | 0,658 | 0,601 | **0,621** | | |
| | 12 | 0,611 | 0,561 | 0,581 | 0,594 | **0,587** | | |

Table 6. Roughness ($R_a$) results for feed rate of 0.15 mm/rev

| Material | Piece | Measurement 1 (µm) | Measurement 2 (µm) | Measurement 3 (µm) | Measurement 4 (µm) | Average per piece | Total average | Standard deviation |
|---|---|---|---|---|---|---|---|---|
| **Hard metal** | 13 | 0,947 | 0,954 | 1,012 | 0,993 | **0,977** | **0,901** | **0,073** |
| | 14 | 0,876 | 0,912 | 0,786 | 0,885 | **0,865** | | |
| | 15 | 0,822 | 0,901 | 0,791 | 0,928 | **0,861** | | |
| **Cermet** | 16 | 0,943 | 0,893 | 0,928 | 0,937 | **0,937** | **0,988** | **0,049** |
| | 17 | 1,019 | 1,008 | 0,998 | 1,022 | **1,012** | | |
| | 18 | 1,034 | 1,004 | 1,027 | 1,037 | **1,026** | | |

Figure 4 shows a graphic with the mean values and standard deviation obtained from the experiments. It could be observed that roughness $R_a$ has a behavior approximately linearly, i.e. it increases with *feed rate*. Another aspect is that hard metal had better performance compared to Cermet.
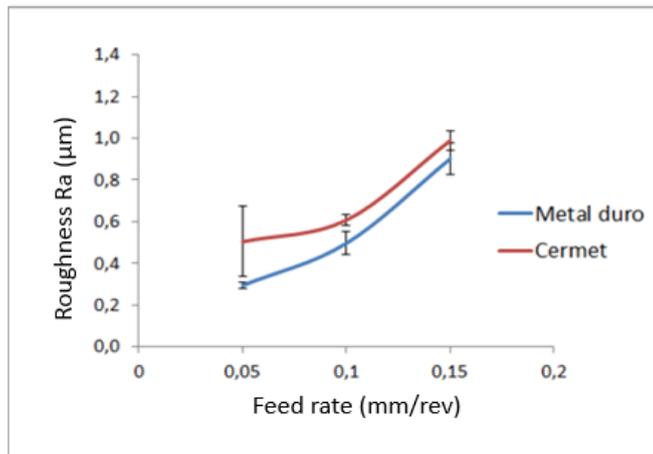


Figure 4: Average Roughness ($R_a$) and Standard Deviation in function of *feed rate* (mm/rev) .
Source: own author.

Tables 7, 8 and 9 show the measured values and standard deviation for the parameter $R_q$, where it could be observed that the parameter has a similar behavior when compared to $R_a$. Figure 10 shows the mean values and standard deviation.

Table 7. Roughness ($R_q$) results for *feed rate* of 0.05 mm/rev

| Material | Piece | Measurement 1 (µm) | Measurement 2 (µm) | Measurement 3 (µm) | Measurement 4 (µm) | Average per piece | Total average | Standard deviation |
|---|---|---|---|---|---|---|---|---|
| **Hard metal** | 01 | 0,341 | 0,349 | 0,353 | 0,357 | **0,350** | **0,363** | **0,019** |
| | 02 | 0,355 | 0,356 | 0,354 | 0,391 | **0,364** | | |
| | 03 | 0,365 | 0,362 | 0,365 | 0,409 | **0,375** | | |
| **Cermet** | 04 | 0,474 | 0,844 | 0,816 | 0,491 | **0,656** | **0,609** | **0,173** |
| | 05 | 0,852 | 0,816 | 0,423 | 0,610 | **0,675** | | |
| | 06 | 0,543 | 0,452 | 0,442 | 0,543 | **0,495** | | |

Table 8. Roughness ($R_q$) results for *feed rate* of 0.10 mm/rev

| Material | Piece | Measurement 1 (µm) | Measurement 2 (µm) | Measurement 3 (µm) | Measurement 4 (µm) | Average per piece | Total average | Standard deviation |
|---|---|---|---|---|---|---|---|---|
| Hard metal | 07 | 0,655 | 0,505 | 0,695 | 0,702 | 0,639 | **0,599** | **0,065** |
| | 08 | 0,612 | 0,563 | 0,628 | 0,621 | 0,606 | | |
| | 09 | 0,558 | 0,538 | 0,598 | 0,515 | 0,552 | | |
| Cermet | 10 | 0,724 | 0,735 | 0,823 | 0,710 | 0,748 | **0,740** | **0,038** |
| | 11 | 0,732 | 0,736 | 0,800 | 0,731 | 0,750 | | |
| | 12 | 0,759 | 0,693 | 0,710 | 0,726 | 0,722 | | |

Table 9. Roughness ($R_q$) results for feed rate of 0.15 mm/rev

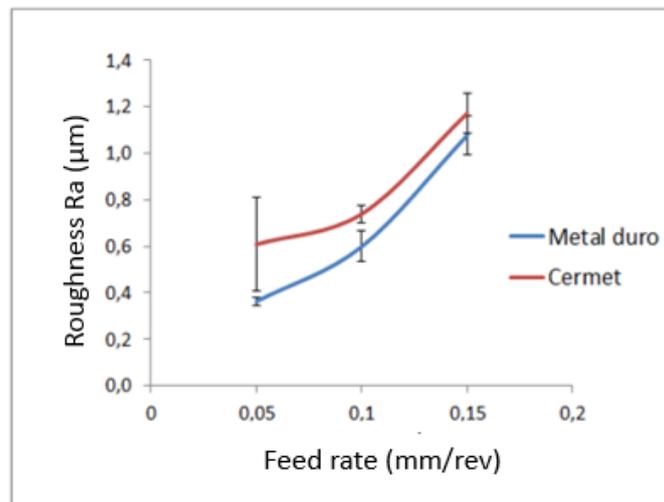| Material | Piece | Measurement 1 (µm) | Measurement 2 (µm) | Measurement 3 (µm) | Measurement 4 (µm) | Average per piece | Total average | Standard deviation |
|---|---|---|---|---|---|---|---|---|
| Hard metal | 13 | 1,115 | 1,124 | 1,207 | 1,175 | 1,155 | **1,0776** | **0,080** |
| | 14 | 1,057 | 1,105 | 0,946 | 1,069 | 1,044 | | |
| | 15 | 1,001 | 1,088 | 0,949 | 1,095 | 1,033 | | |
| Cermet | 16 | 1,01 | 1,107 | 1,05 | 1,095 | 1,066 | **1,173** | **0,084** |
| | 17 | 1,229 | 1,211 | 1,189 | 1,219 | 1,212 | | |
| | 18 | 1,244 | 1,214 | 1,247 | 1,256 | 1,240 | | |



Figure 5: Average Roughness ($R_q$) and Standard Deviation in function of *feed rate* (mm/rev) .
Source: own author.

Tables 10, 11 and 12 present the measured values and standard deviation of the measured values of the experiments for the parameter $R_z$, with the data of these tables a plot was plotted, where it is observed the same behavior for all the other roughness, $R_a$ and $R_q$. It is also influenced by the *feed rate*, i.e., decreasing with *feed rate* decreases.

Table 10. Roughness ($R_z$) results for *feed rate* of 0.05 mm/rev

| Material | Piece | Measurement 1 (µm) | Measurement 2 (µm) | Measurement 3 (µm) | Measurement 4 (µm) | Average per piece | Total average | Standard deviation |
|---|---|---|---|---|---|---|---|---|
| Hard metal | 1 | 1,652 | 1,651 | 1,687 | 1,704 | **1,674** | 1,766 | 0,121 |
| | 2 | 1,705 | 1,785 | 1,686 | 1,871 | **1,762** | | |
| | 3 | 1,985 | 1,746 | 1,725 | 1,999 | **1,864** | | |
| Cermet | 4 | 2,463 | 4,117 | 3,874 | 2,613 | **3,267** | 2,996 | 0,869 |
| | 5 | 4,117 | 3,867 | 2,071 | 3,809 | **3,466** | | |
| | 6 | 2,479 | 2,072 | 2,086 | 2,385 | **2,256** | | |

Table 11. Roughness ($R_z$) results for *feed rate* of 0.10 mm/rev

| Material | Piece | Measurement 1 (µm) | Measurement 2 (µm) | Measurement 3 (µm) | Measurement 4 (µm) | Average per piece | Total average | Standard deviation |
|---|---|---|---|---|---|---|---|---|
| Hard metal | 7 | 2,915 | 2,361 | 3,184 | 3,200 | **2,915** | | |
| | 8 | 2,701 | 2,681 | 2,783 | 2,758 | **2,731** | **2,671** | **0,331** |
| | 9 | 2,242 | 2,347 | 2,642 | 2,232 | **2,366** | | |
| Cermet | 10 | 3,072 | 3,839 | 3,633 | 3,356 | **3,475** | | |
| | 11 | 3,238 | 3,335 | 3,477 | 3,519 | **3,392** | **3,589** | **0,322** |
| | 12 | 4,185 | 3,963 | 3,809 | 3,647 | **3,901** | | |

Table 12. Roughness ($Rz$) results for feed rate of 0.15 mm/rev

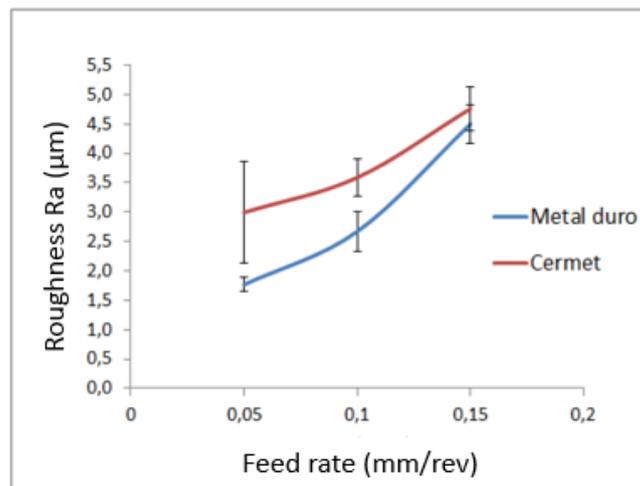| Material | Piece | Measurement 1 (µm) | Measurement 2 (µm) | Measurement 3 (µm) | Measurement 4 (µm) | Average per piece | Total average | Standard deviation |
|---|---|---|---|---|---|---|---|---|
| Hard metal | 13 | 4,311 | 4,458 | 5,197 | 4,714 | **4,670** | | |
| | 14 | 4,475 | 4,815 | 4,037 | 4,225 | **4,388** | **4,500** | **0,323** |
| | 15 | 4,705 | 4,455 | 4,116 | 4,487 | **4,441** | | |
| Cermet | 16 | 4,476 | 4,083 | 4,487 | 4,131 | **4,294** | | |
| | 17 | 5,232 | 5,059 | 4,791 | 4,865 | **4,987** | **4,761** | **0,379** |
| | 18 | 5,023 | 4,919 | 5,025 | 5,042 | **5,002** | | |



Figure 6: Average Roughness ($R_z$) and Standard Deviation in function of *feed rate* (mm/rev) .
Source: own author.

## 4. CONCLUSIONS

It could be verified that the variation of the *feed rate* in the turning directly influences the surface finish of the steel C-110 steel. For all the roughness parameters analyzed, $R_a$, $R_q$ and $R_z$, roughness decreased with *feed rate decreasing* as expected.

In relation to the materials of the cutting tools, the hard metal presented a better finish results when compared to the cermet. Average values found for $R_a$, showed results 41.66% better compared to cermet, when using *feed rate* of 0.05 mm/rev, for 0.10mm/rev $R_a$ results were 18.30% better and at last, for 0.15 mm/rev, 8,80 %.

Among the *feed rates* analyzed, it was not possible to obtain a $R_a$ value less than the normalized 0.250 µm. Best result found was of 0.277 µm using the hard metal and 0.05 mm / rev as *feed rate*. It could be observed in the experiments that it was not possible to replace the gridding by the turning operation using the methodology applied for this work. However, results were relatively close, with a percentage difference of 17,00%. Further studies are necessary to verify the possibility of achieves the normalized roughness of 0.25 um using just turning operation. For instance, a more robust machine and changes in cutting parameters, just as cutting speed, depth of cut, cutting fluid, etc., could help to achieve the values found in the grinding process.

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