Proceedings of the 7th International Conference on Mechanics and Materials in Design
Albufeira/Portugal 11-15 June 2017. Editors J.F. Silva Gomes and S.A. Meguid.
Publ. INEGI/FEUP (2017)

PAPER REF: 6474

RESPONSE SURFACE METHODOLOGY APPLIED TO A HARD TURNING PROCESS USING WIPER GEOMETRY TOOL

Gabriela Belinato(*), Rachel Campos Sabioni, Taynara Incerti de Paula, Paulo Henrique Campos, Pedro Paulo Balestrassi

Department of Industrial Engineering, Federal University of Itajubá, Itajubá, Brazil
(*)*Email:* gabrielabelinato@gmail.com

ABSTRACT

The use of hard turning materials has been increasing over the last few years. Due to the development of special geometries and tool material with high hardness and wear resistance at high temperatures, added to the development of machine tools with greater rigidity and dimensional precision in high rotations, it has been possible to machining these materials by the turning process. Conventional studies of tool life and roughness of machined surfaces by the turning process takes into account the influence of several input factors such as cutting speed, cutting feed and machining depth in isolation, which requires a large number of tests. To consider the simultaneous variation of many input factors to construct predictive models for responses of interest we can use the Design of Experiments (DOE). In this way, this study deals specifically with the workpiece surface roughness (Ra) and tool life (T) in the turning process of hardened AISI H13 (54 HRC) steel by the ceramic tool CC650. We obtained the mathematical models by the Response Surface Methodology (RSM) using as variables of process cutting speed, cutting feed and machining depth. According to experiments, we observed cutting feed (f) is the main effect of roughness (Ra), while cutting speed (Vc) is the factor with major influence on the tool life (T).

Keywords: hard turning, cutting tools, AISI H13 steel, response surface methodology.

INTRODUCTION

According to Mohamed et al. (2012) and Lahiff et al. (2007), machining of hardened materials is the machining of materials which hardness is higher than 45 HRC. This process is widely used in the manufacturing of bearings, gear shafts, special cutting tools, dies, molds, among others, to improve the wear resistance of these components (FARIAS, 2009). Traditionally, grinding process is used in turning, however, due to the development of ultra-hard materials for machining tools, such as ceramics, and machine tools with high stiffness and dynamic stability, the finishing operations on hardened materials by turning process have become feasible (LAHIFF et al., 2007).

In addition to enable the machining of complex geometries, turning also presents other advantages when compared to the grinding process, such as high material removal rate, greater flexibility, less damage to the subsurface layer due to the smaller contact area and contact time of the tool with the workpiece. In addition, another advantage is the greater agility in the process, since a larger portion of the workpiece geometry can be machined in a single machine preparation (STEPHENSON; AGAPIOU, 2006).

As said in Pampuch et al. (1995), materials used in manufacturing of chip-cutting tools applied to the machining of hardened materials should combine high efficiency with increasing chip removal rate. In order to perform a chip-cutting operation it is essential that cutting tools resist the working conditions imposed during the machining process. Constituent material of the tool must possess some characteristics to respond effectively to the cutting process, such as hot hardness, toughness, wear resistance and chemical stability. Generally, cutting tool hardening improves the resistance to wear, nevertheless causes a tenacity drop (KOMANDURY, 1994).

Ceramics are one of the classes of material for cutting tools, which have high potential for finishing operations with high chip removal rates, since they are low cost and exempt from the addition of strategic materials (BARTARYA et al., 2011).

There are several factors able to influence the tool life and roughness of machined surfaces by turning process, such as cutting speed, cutting feed, machining depth and cutting tool geometry. In conventional studies, these factors are usually considered in isolation, which requires large number of tests, high consumption of material and tools, and many machine hours, that makes the experimentation costs prohibitive (BOUACHA et al., 2010).

In this context, there is the Design of Experiments (DOE), methodology that allows establishing an adequate functional relationship between the tool life or the workpiece roughness of cutting parameters, considering the simultaneous variation of input factors to construct predictive models for responses of interest (CAMPOS, 2015). This statistical approach consists of planning experiments able to generate fitting data for an effective analysis, resulting in valid and objective conclusions (MONTGOMERY, 2005).

In this sense, to investigate the behavior of tool life (T) and surface roughness (Ra) of the CC 650 ceramic, we will conduct hard turning essays on AISI H13 steel, by applying the Response Surface Methodology (RSM)

LITERATURE REVIEW

Machining parameters

Machining parameters for turning hardened materials are often used on finishing operations, in which are employed low values of machining depth (ap), compatible cutting feed (f) values with the desired finishing pattern and cutting speed (Vc) levels lower than those used in non-hardened materials.

Several researchers have been carrying out investigations about the effect of cutting parameters, cutting speed, cutting feed and machining depth on the workpiece roughness, residual stresses, tool wear and its hard turning combinations, as shown in Table 1.

Table 1 - Material, hardness and machining parameters in hard metals turning processes with ceramic tools.

Author	**Material/ Hardness/Tool**	**Cutting parameter**
Lalwani et al. 2008	MDN 250 /50/ceramics	**Vc**= (55, 74, 93 m/min); **f**= (0.04, 0.08, 0.12 mm/rev); **ap**= (0.1, 0.15, 0.2 mm).
Gaitonde et al. 2009	AISI D2/61/ceramics	**Vc**= (80, 115, 150 m/min); **f**= (0.05, 0.10, 0.15 mm/rev);
Yen et al. 2004	AISI 1020/54 ceramics	**Vc**= (300 m/min); **f**=(0.145 mm/rev);
Bajic et al. 2012	42CrMo4/60/ ceramics	**Vc**= (120, 140 m/min); **f**= (0.1, 0.2 mm/rev); **ap** = (1.0, 1.5 mm).

Source: Campos, 2015.

From Table 1 we observe the most frequently cutting speed (Vc) values are on the range of 100 to 200 m / min. The cut-off depth (ap) range normally used on turning of hardened materials is among 0.15 and 0.20 mm. Cutting feed (f) is the most important machining parameter on turning process, because it causes the highest impact on the finish of machined component. In this way, the cutting feed (f) is estimated as a function of the tool tip radius (rε) and the desired roughness pattern in the machined component.

Response Surface Methodology

According to Montgomery (2005), the Response Surface Methodology (RSM) is a set of mathematical and statistical tools used for modeling and analysis of problems in which the objective is to optimize a response of interest, influenced by several variables.

For most problems, relations between the response and independent variables are unknown. Thus, the first step is to find a suitable approximation to represent a response of interest as a function of the process variables. This type of relation is normally described by polynomial functions. In this way, if the response is well modeled by a linear function, the first-order model, as described on Eq. (1), can represent the approximate ratio.

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_k x_k + \varepsilon \quad (1)$$

where:

y - Response of interest
x_i - Independent variables
β_i - Coefficient
k - Number of independent variables
ε - Experimental error
If the system has curvature, then a higher degree polynomial should be used, as the second order model described by Eq. (2).

$$y = \beta_0 + \sum_{i=1}^{k} \beta_i x_i + \sum_{i=1}^{k} \beta_{ii} x_i^2 + \sum_{i<j} \sum \beta_{ij} x_i x_j + \varepsilon \quad (2)$$

Almost all response surface problems use one or both above models. Furthermore, it is unlikely the polynomial model behaves as a suitable approximation for the entire experimental space covered by the independent variables. However, for a specific region, these models have been efficient.

The experimental design for data collection most used in Response Surface Methodology is Central Composite Design (CCD). A CCD for k factors is a matrix composed by three distinct groups of experimental elements: a complete factorial (2k) or fractionated (2k-p, p is the desired fraction of the experiment), a set of central points (m) and, additionally, a group of extra levels called axial points - 2k (Figure 1). The number of axial points on a CCD is equal to twice the number of factors and represent their extreme values. Depending on the location of axial points, the CCD can be circumscribed, inscribed or face-centered.

Several researchers have frequently used Response Surface Methodology (RSM), which is one of the main techniques of Design and Analysis of Experiments, contributing to better understanding the relations between variables in several manufacturing processes. In this sense, numerous success cases of applying this methodology are described in literature, such as CORREIA et al. (2005), PALANI and MURUGAN (2007), RODRIGUES et al. (2008).

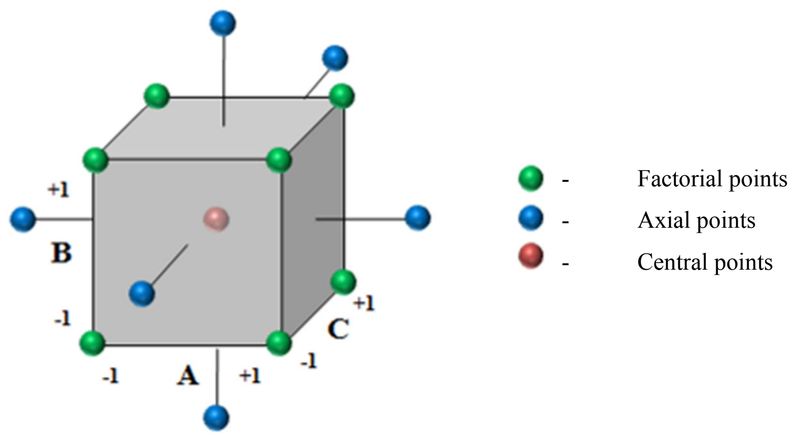

Fig. 1 - A Central Composite Design (CCD) for three factors.

METHODOLOGY

Experimental design

This work adopted cutting speed (Vc), cutting feed (f) and machining depth (ap) as control variables. They are admittedly recognized as the most important variables, since they strongly influence the turning process, mainly on the workpiece surface finish and the tool wear.

We planned the experiments following a Central Composite Design (CCD), created for three parameters at two levels, resulting in 19 experiments. At the end of the tests, the parameter levels were set, as shown in Table 2.

Table 2 - Control variables and work levels.

Control variables	**Symbol**	**Levels**				
		-1.682	**-1**	**0**	**1**	**1.682**
Cutting speed (m/min)	Vc	57.39	100.00	162.50	225.00	267.61
Cutting feed (mm/rev)	F	0.06	0.10	0.16	0.22	0.24
Machining depth (mm)	Ap	0.09	0.15	0.225	0.33	0.39

Experimental proceeding

The workpiece material was AISI steel H13 with a hardness of approximately 54 HRC, which chemical composition includes C (0.370-0.420%); Mn (0.200-0.500%); Si (0.080-0.120%); Cr (0.050-0.055%); V (0.080-0.012%) and Mo (0.012-0.017%). We conducted the essays on a turning center MHP Kingsbury, with 18 kW power and maximum rotation of 4500 rpm, using a CC650 ceramic tool, which chemical composition is described on Table 3.

Table 3 - Chemical composition of CC650.

Sandvik Coromant Tool		
Ceramic	**ISO Geometry**	**Composition**
CC 650	CNGA120408 T01020	70% Al_2O_3 + Ti [22.5% C, 7.5% N]

Roughness measurement (Ra)

We characterized the turned surfaces through the most common technique of surface microgeometry analysis, called rugosimetry. Roughness parameters values according to ISO 4287/1 were obtained through the Hommeltester-T 1000 needle roughymeter.

Tool life measurement (T)

Flank wear was measured for different insertions in relation to the cutting time for different combinations of cutting parameters. We found the classic process of tool wear, which followed with the increase of cutting parameters, especially cutting speed.

We obtained the end of tool life (T) in minutes by multiplying the total number of passes by cutting time (Tc) in each pass, such as showed on Eq. (3).

$$Tc = \frac{l_f \cdot \pi \cdot d}{1000 \cdot f \cdot Vc} \quad [\text{min}] \tag{3}$$

Where:

l_f - Workpiece lenght = 100 mm,
d - Workpiece diameter = 49 mm,
f - Cutting feed [mm /rev],
Vc - Cutting speed [m/min]

RESULTS AND CONCLUSIONS

As shown in Figure 2 (A) and (B), the main types of wear were flank wear and crater wear. From analysis of Figure 2 (B), we observe cutting edges were weakened due to the change of tool geometry because of the intense crater wear, which helped the occurrence of micro-slabs. These micro-plates affected the formation of severe abrasive marks in flank region, influencing the roughness of machined workpiece, as shown in Figure 2 (A).

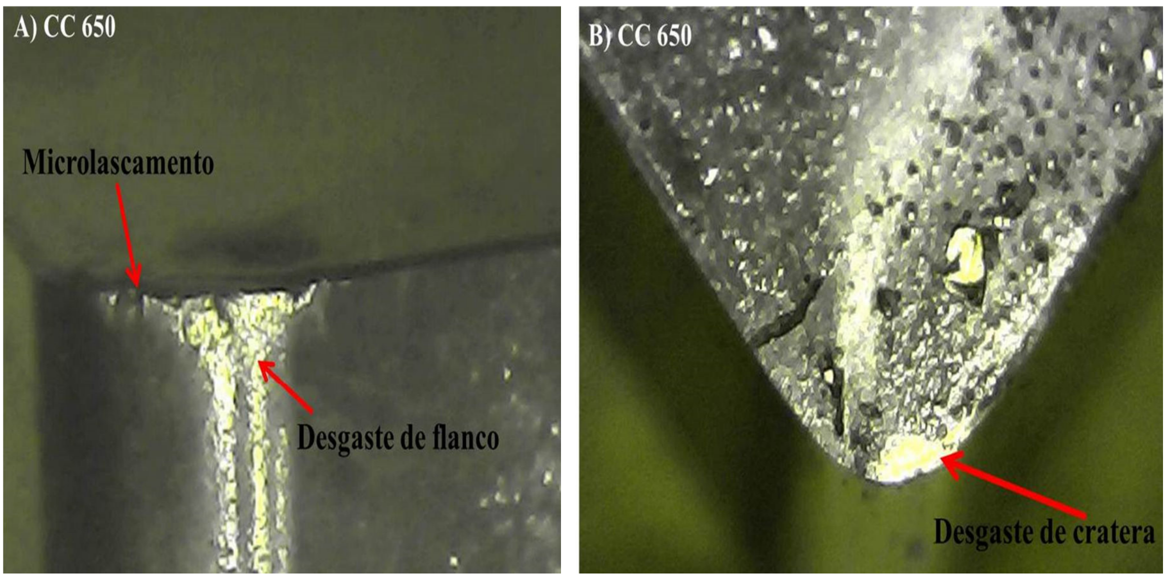

Fig. 2 - CC 650: (A) Clearance surface and (B) Output surface.

Figure 3 shows the machined surface representation for the studied conditions at the end of tool life.

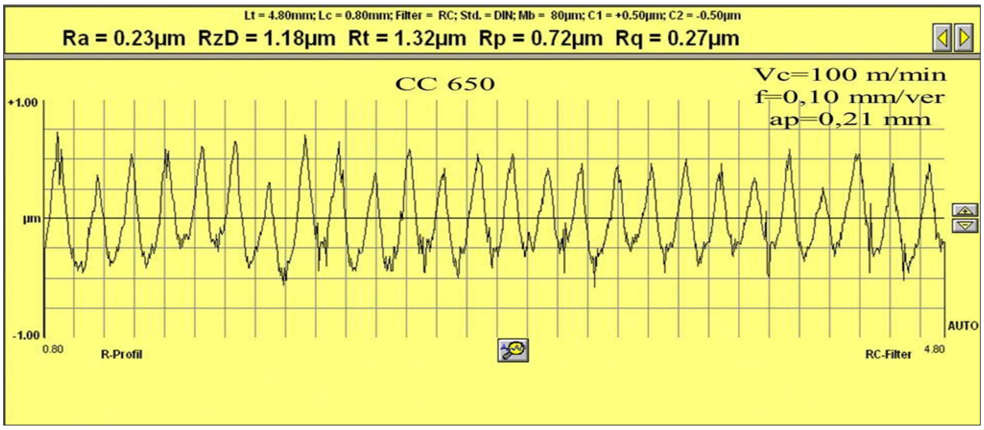

Fig. 3 - Representation of machined surface at the end of CC 650 tool life.

As shown in Table 4, the analysis of experiments 10 and 11 shows the highest roughness value of 0.65 (μm) for a Vc = 267.00 (m/min), f = 0.16 (mm/rev) and ap = 0.24 (mm), and a lower roughness value of 0.26 *(μm),* for Vc = 162.50 (m/min), f = 0.05 (mm/rev) and ap = 0.24 (mm). Comparing the results, we found for the smallest advance, the lowest workpiece roughness value (Ra).

Another example is on experiments 11 and 12. For Vc = 162.50 (m/min), f = 0.05 (mm/rev) and ap = 0.24 (mm), the roughness values of the experiment 11 is 0.26 *(μm)* and the values of experiment 12, for Vc = 162.50 (m/min), f = 0.26 (mm/rev) and ap = 0.24 (mm) is 1.63 *(μm)*.

Table 4 - Experimental matrix (CCD) responses for CC 650 tool.

Experiment	***T* *(min)***	***Ra* *(μm)***
1	59.00	0.23
2	31.25	0.40
3	48.50	1.62
4	26.00	1.72
5	58.00	0.32
6	26.25	0.24
7	48.50	1.74
8	26.00	1.67
9	56.50	0.72
10	21.50	0.65
11	36.00	0.26
12	38.50	1.63
13	47.25	0.96
14	45.00	0.92
15	40.50	0.82
16	41.00	0.83
17	42.00	0.81
18	41.50	0.82
19	42.00	0.83

We observed cutting feed (f) exerts the greatest influence on the roughness (Ra) values, since, when maintaining values of Vc and ap for the lowest cutting feed (f), we obtained the lowest workpiece roughness (Ra), as presented in Figure 4.

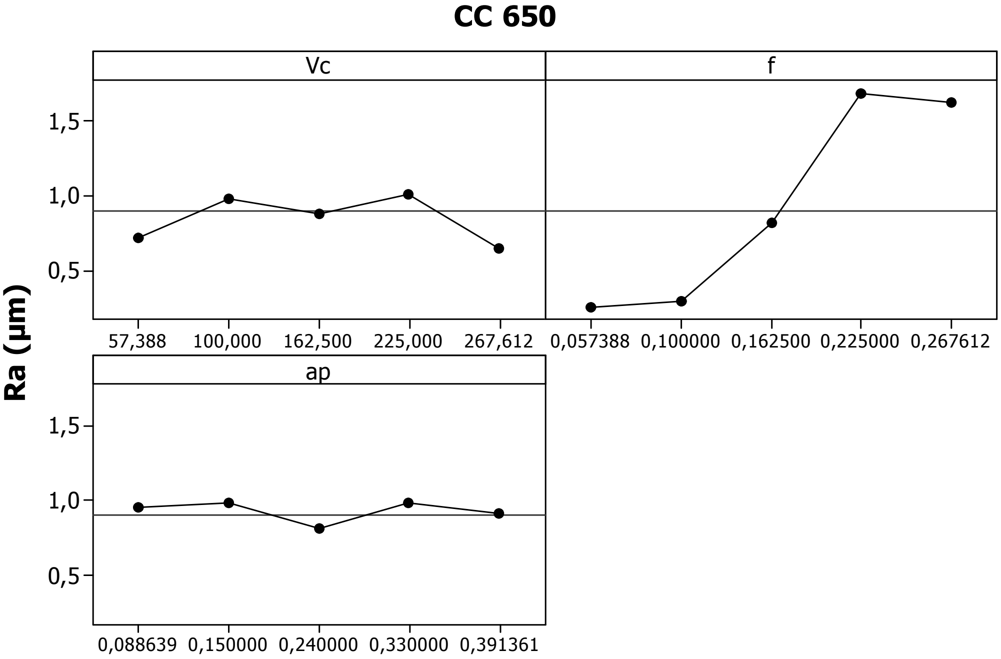

Fig. 4 - Main effects for Ra (µm).

Table 4 also shows the tool life values. On experiment 11, for a tool life of 36 min, Vc = 162.50 (m/min), f = 0.05 (mm/rev) and ap = 0.24 (mm), while on experiment 12 we obtained a tool life of 38,5 min, for Vc = 162.50 (m/min), f = 0.26 (mm/rev) and ap = 0.24 (mm). On experiments 7 and 8 (Vc = 100 and 225 m/min) and 9 e 10 (Vc = 57 and 267 m/min, axial point), we got higher values of tool life for lower cutting speed, suggesting Vc is the main effect on the tool life.

Figure 5 shows the main effects for tool life (T) as a function of cutting speed (Vc), cutting feed (f) and machining depth (ap), which confirms the data from Table 4 that Vc is the factor which has major influence on the tool life.

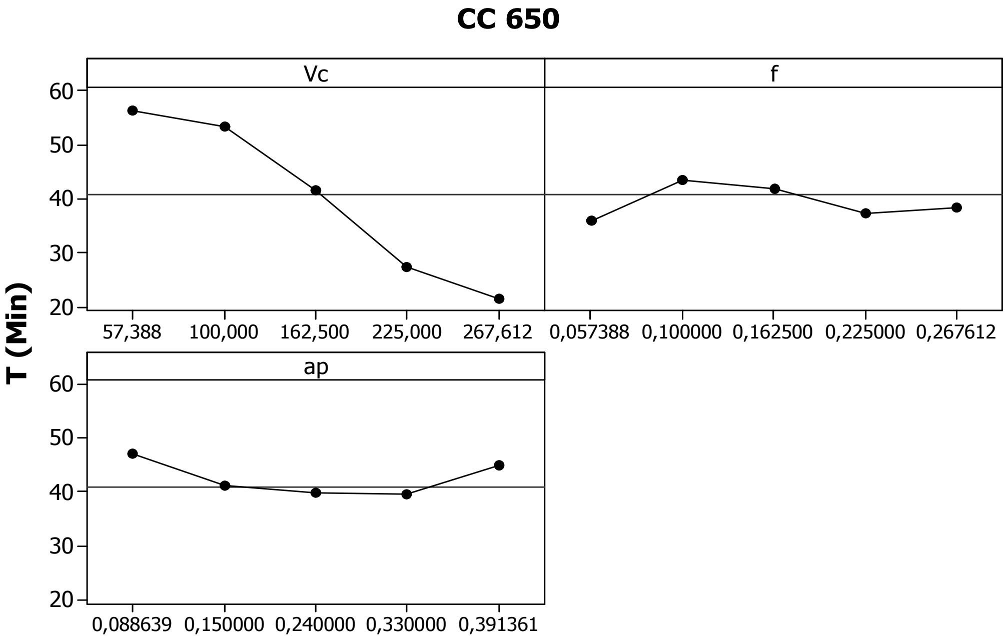

Fig. 5 - Main effects for T (min).

ACKNOWLEDGMENTS

The authors gratefully acknowledge the funding by FAPEMIG, CAPES, CNPq; the University of Aveiro and Professor João Paulo Davim.

REFERENCES

[1]-Bartarya, G.; Choudhury, G. S. K. (2012). State of the art in hard turning, International Journal of Machine Tools & Manufacture, Vol. 53, p. 1-14.

[2]-Bouacha K, Yallese MA, Mabrouki T, Rigal JF (2010) Statistical analysis of surface roughness and cutting forces using response surface methodology in hard turning of ABNT 52100 bearing steel with CBN tool. Int J Refract Metals Hard Mater, 28:361-349.

[3]-Campos PH. (2015). Metodologia DEA-OTS: uma contribuição para a seleção ótima de ferramentas no torneamento do aço ABNT H13 endurecido. Tese de doutorado. Programa de Pós-Graduação em Engenharia de Produção, 225 p.

[4]-Correia, D. S.; Gonçalves, C. V.; Cunha, J. R.; Ferraresi, V. A. (2005). Comparison Between Genetic Algorithms and Response Surface Methodology in GMAW Welding Optimization, Journal of Materials Processing Technology, Vol. 160, p. 70-76.

[5]-Farias, A. D. (2009). Análise da Tensão Residual e Integridade Superficial no Processo de Torneamento em Material Endurecido do Aço ABNT 8620 Cementado. Dissertação de Mestrado - Escola Politécnica da Universidade de São Paulo.

[6]-Komandury, R. (1994). Ceramic Cutting Tools, Friction Wear Ceramics, Marcel Dekker Inc, p. 289-311.

[7]-Lahiff, C.; Gordon, S.; Phelan, P. (2007). PCBN tool wear modes and mechanisms in finish hard turning. Robotics and Computer-Integrated Manufacturing. Vol. 23, p. 638-644.

[8]-Mohamed, W. A.; Salim, B.; Mohamed, A. Y.; Tarek M.; Jean-François, R. (2012). Surface roughness and cutting forces modeling for optimization of machining condition in finish hard turning of AISI 52100 steel, Journal of Mechanical Science and Technology, Vol. 26, n.12, p. 4105 - 4114.

[9]-Montgomery, D. C. (2005). Designs and Analysis of Experiments. John Wiley & Sons.

[10]-Palani, P. K.; Murugan, N. (2007). Optimization of weld bead geometry for stainless steel claddings deposited by FCAW. Journal of Materials Processing Technology, Vol. 190, n. 1-3, p. 291-299.

[11]-Pampuch, R.; Lis, J. (1995) Ceramic Charting the Future, Techna, p. 2327-2334.

[12]-Rodrigues, L. O.; Paiva, A. P.; Costa, S. C. (2008). Otimização do processo de soldagem com eletrodo tubular através da análise da geometria do cordão de solda. Soldagem & Inspeção, Vol. 13, n. 2, p. 118-127.

[13]-Stephenson, A. D.; Agapiou, J. S. (2006). Metal Cutting Theory and Practice. Second ed. Taylor & Francis.