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CHARACTERISATION OF THE EFFECTIVE CLAMPING FORCE OBTAINED BY THE APPLICATION OF VACUUM TECHNIQUES TO DIFFERENT MATERIAL PROBES

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ABSTRACT

A good clamping system is basic to guarantee the correct machining of parts. In particular, for the vacuum clamping systems, it is fundamental to ensure that the clamping forces generated are sufficient to support the parts while being machined. In the present paper are presented the results of a set of experiments performed on a work bench in order to characterise the effective clamping forces obtained by the application of vacuum clamping techniques to 7 different materials. The rationality of this study lies on the need to study the response given by the materials to Normal and Tangential stresses, in order to define the suitability of each of them for the usage as flexible clamping ends. The study finishes with the comparison of the results obtained with the theoretical thresholds needed during the machining of two metallic parts: one made of steel and another made of aluminium.

Keywords: Clamping, flexible manufacturing, machining, orthogonal cutting

1. INTRODUCTION

Previous experiences of the authors in the field of flexible subjection methods showed that many flexible clamping devices can lead to marks or remains in the surface of the parts that have to be machined; for example, leading to infiltration of wax in the parts to be machined[1].Therefore, the objective of this study is to explore the possibilities of vacuum clamping devices in the search for flexible clamping systems without side-effects in the parts.

Certainly, the effective force reached by a vacuum clamping device that only holds the part by its lower plain surface will depend on the combination of the Normal force (F_n) gained by the vacuum generation and on the Tangential force (F_t) resulting from the friction parameters. Assuming that the different materials in the study have a non negligible anisotropic and heterogeneous behaviour, in order to analyse its level of potential response it has been necessary to assess the actual F_n and F_t in a test bench.

As the finality of the study is to bring light to the development of clamping devices for metallic parts in which the materials tested in the study would perform as the clamping ends, the level of response will have to be compared to the machining cutting requirements of metallic parts; in the present study, steel and aluminium. In order to calculate the theoretical thresholds for both metals, in this paper are utilised equations according to the orthogonal cutting model[2], which allows to evaluate the cutting forces both in the normal and tangential direction.

This theoretical implementation becomes very useful to provide theoretical requirements prior to enter into experimentation in an actual Machine tool. Also, the figures obtained reveal information that could be used in a further exploration for the subjection of non-planar surfaces.

2. EXPERIMENTAL DISPOSITION

The experimental test bench utilised for the present study has been a simple disposition of a force lever equipped with a dynamometer, capable of introducing forces in the Normal and Tangential directions. These forces have been applied to the 7 different materials showed in the Table 1 below which, in their turn, were vacuum clamped to a planar suction system.

Table 1. Different Materials utilised in the tests

Material 1	Steel
Material 2	Aluminium
Material 3	Injected Polyamide
Material 4	Wood
Material 5	Laser Sintered Polyamide
Material 6	Low density Polystyrene
Material 7	Polyurethane Resin

The experimental methodology consists on the application of a load in two principal directions of the vacuum device; namely, the Normal and Tangential directions. The dynamometer registers the maximum load applied until the lost of contact between the material and the vacuum generation; which is taken as the threshold operational value of each material. Figure 1 below presents some of the material probes of the different materials used in the experimentation.

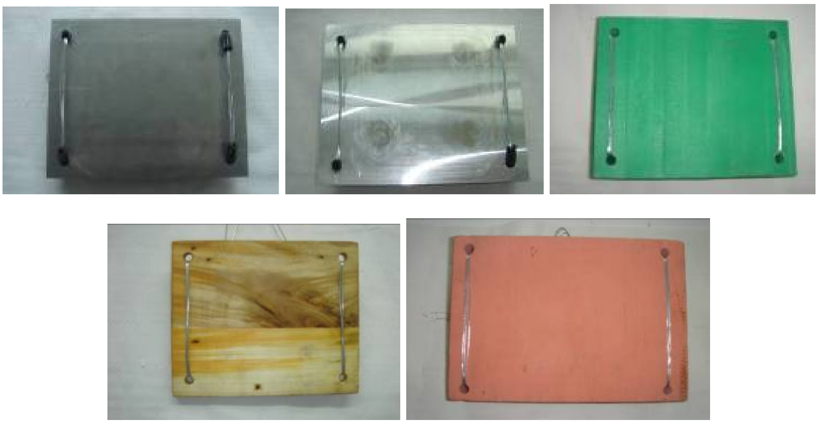


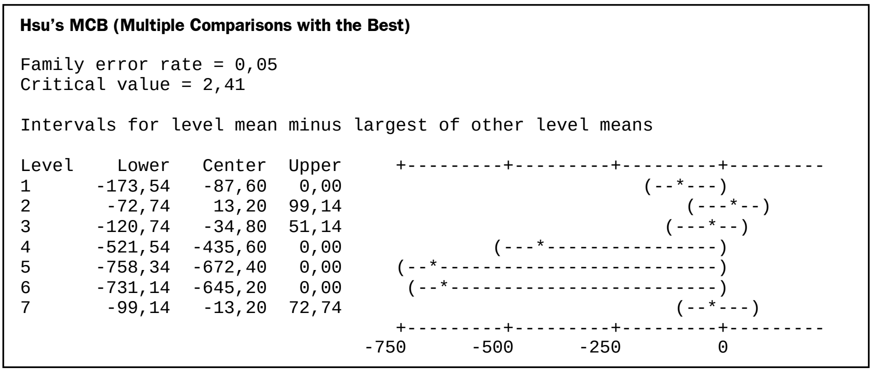
Figure 1. Some Material probes utilised in the tests

3. ANALYSIS OF RESULTS OF THE TESTS LOADING IN NORMAL DIRECTION TO THE VACUUM CLAMPING

The objective of this analysis has been to evaluate if there is any significant difference between the responses in the maximum Normal force supported by each material.

After the exploratory abnormalities detection by means of Boxplots and the disclosure of significant differences between the results obtained with different materials, the *Analysis of the Variance* and the *Multiple comparisons with the Best (MCB)* demonstrate that the Materials 1, 4, 5 and 6 facilitate lower maximum clamping effective forces.

The experimental numerical values of the maximum F_n oscillate between 1009,2N (Material 2) and 336,8N (Material 6). The relative response for each material can be inferred from the MCB presented in Figure 2.



Hsu's MCB (Multiple Comparisons with the Best)

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Family error rate = 0,05
Critical value = 2,41

Intervals for level mean minus largest of other level means

Level    Lower    Center  Upper    +---------+---------+---------+---------
1      -173,54    -87,60   0,00                           (--*---)
2       -72,74     13,20  99,14                               (---*--)
3      -120,74    -34,80  51,14                             (---*--)
4      -521,54   -435,60   0,00             (---*----------------)
5      -758,34   -672,40   0,00    (--*--------------------------)
6      -731,14   -645,20   0,00     (--*-------------------------)
7       -99,14    -13,20  72,74                              (--*---)
                                   +---------+---------+---------+---------
                                -750      -500      -250         0
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Figure 2. MCB for the Normal force tests

4. ANALYSIS OF RESULTS OF THE TESTS LOADING IN TANGENTIAL DIRECTION TO THE VACUUM CLAMPING

In line with the previous chapter, the objective of this part of the analysis has been to evaluate if there is any significant difference between the responses in the maximum Tangential force supported by each material in the study.

In this case, after the Boxplot analysis and the *Analysis of the Variance;* the *Multiple comparisons with the Best (MCB)* demonstrate that this time the Materials 3, 4, 5 and 6 facilitate significantly lower maximum clamping effective forces than the rest.

The numerical values of the maximum F_t obtained are comprised between 301,2N (Material 2) and 203,6N (Material 6).

5. CALCULATION OF THEORETICAL THRESHOLDS OF CUTTING FORCES

The geometry of almost all the machining processes is complex. The orthogonal cutting model[3, 4] is a simplified model that does not take into account some geometrical aspects, but describes the mechanics of the process with enough precision, using only two dimensions, although the machining process is three-dimensional. This model has been applied to analyse the cutting forces between the tool and the part; with the objective of evaluating the cutting forces that the clamping system has to support.

The following sections show the results obtained when calculating the cutting forces for a part made of steel and a part made of aluminium. For both of them it has been considered a detachment angle γ of 10º and a chip section of 0,3 mm^2.

5.1. Steel

Considering a steel 4130 AISI with the following properties:

Rupture load (σ_r) = 670 N/mm^2 Brinell hardness= 197 HB

In tables, there are found the values τ_s, the constant C and the coefficient of friction μ. Therefore:

μ= 0,99 C= 76,20º τ_s = 640 N/mm^2

With this information and knowing that the forces F_γ and $F_{\gamma n}$ are linked to the coefficient of friction μ; it is obtained: $\tau = arctg\mu = 44{,}71^{\circ}$

From Ernst [5] and Merchant [6] models: $\phi = 20{,}75^{\circ}$

With this data, following the models presented[7], it is possible to calculate the components of the resulting force F in the cutting direction (F_t) and the normal direction (F_n), and the resulting force F:

F_n= 593,28N F_t= 785,28N F=984,20N

5.2. Aluminium

Considering an aluminium 3005-H18 with the following properties:

Rupture load (σ_r) = 240 N/mm^2 Brinell hardness = 65 HB

In this case, as suggested by Micheletti[3], the calculation has been made by means of the cutting pressure k_s. The values of τ_s and k_s are found in graphics and tables:

τ_s = 190 N/mm^2 k_s = 580 N/mm^2

With this information it has been obtained the following values:

F_n= 75,80N F_t= 189,90N F=204,28N

6. CONCLUSIONS

The calculation of the cutting forces has been made following Merchant's equation and the method of the specific pressure. It has been seen that the theoretical effective clamping force requirements for machining steel parts is approximately five times higher than the force required for machining aluminium parts.

The objective has been to study and categorise whether or not each material could act as clamping ends in vacuum clamping systems. The results found show significant differences between the values of effective clamping force achieved by each type of material. In particular, when comparing to the theoretical thresholds calculated, it is demonstrated that the system proposed could not be able to cope with the requirements of steel parts although some of the materials tested could deal with the aluminium needs.

Notwithstanding, the development of vacuum clamping devices for non-planar parts it is feasible for not very demanding materials –such as Aluminium- if the clamping force can be maintained in the contact between the clamping device and the part to be machined. In any case, it would be recommendable to allow a reasonable security factor -depending on the machining process particularities- to guarantee the good operation of the clamping system despite possible unexpected peaks in the load requirements. From another perspective, it is derived that to meet high effective force requirements -such as the steel ones; it would be necessary to implement some auxiliary tangential clamping elements in order to increase the Tangential force obtained.

7. REFERENCES

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