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Forces and Temperatures Distribution Simulated on a Metal Carbide Chip of Cutting

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Abstract: The current tendency in research in very high resistance materials to wearing such as materials used in machining are: Metallic materials (carbide), non-metallic materials (ceramic, nitride), coverings (in mono or multi layers) of material after material, insertions (injection or insertion of material inside material). These materials and methods use sssmainly powders metallurgy in the elaboration. This technology has developed the rationing in the chemical composition and also in the layers. The diversification in compositions brings in naturally a structural variation and consequently, a variation of physic mechanical properties. As the materials form the parts, they are subject to external charges. The aim of our research is, indeed, to relate and to set the material according to its charges. This is what drives one to make one's own material according to the functional requirements (dynamic, thermal, kinematic) of the part. To use this approach, we have chosen the machining board, a part which is always subject to almost extreme external changes (forms, frictions, temperatures...). The board, soldered or detachable, appears in diverse forms (triangular, squared, rounded), with or without chip breakers, of varying geometry related to the piece and forms related to their fixations. Metallic carbide boards are widely used in machining through metal removing. In general, they are made up of WC, of TiC, of Nbc, of Co or other relating materials. In the case of machining standard boards, each of these carbide compositions takes up the whole volume of the board. The use of this methodology in the design of materials to the machining board lies in dividing up the penetrating parts or edges and the support parts. In this way, a rationalization of the volume of the board and, after that, a material economy may be considered. An insertion of noble materials piece may be used in the cutting part, when the other parts may receive materials of acceptable properties but low-priced. The definition of the parts or zones of the board, according to the varied requirements, is made by the method of finished elements taking into consideration functional parameters (v, a, p) and characteristics for materials development (E, υ, ρ) and those of materials for machine-cutting. This design takes also into account the behaviour of interface or inter-zone materials. The present research has enabled us to develop a chipped materials design software for metallic carbide squared boards. In order to confirm the results of the research, a prototype of boards design and elaboration following this method has been realised.

Key words: Machine-cutting, powders metallurgy, insertion of material, covering of material, carbides, ceramics, interfaces of materials, method of finished elements

INTRODUCTION

The component elements of cut materials such as tungsten, titanium, tantalum and many other types have become increasingly rare on the world markets and are therefore expensive. The current tendencies in the research of materials of cut are EURO-PM (1999):

- Non-metal materials (ceramics, nitrides,etc).
- Coatings (deposit into mono or multi-layer of material on material).
- Insertion (injection or insertion of a material).

These methods use conventional metallurgy as well as powders metallurgy in the elaborating process, contributed in the improvement of rationing compositions and even in the layers of compounds.

These cut materials are presented in the majority of the cases in plaques to braze or removable various triangular, square forms, round, etc. The plaques out of metal carbide are worked out by sintering after treatment of the powders composing the agglomerate. In general, they are made up of mono or multi tungsten Carbides (WC), of Titanium (Tic), Tantalum (TAC) and Niobium

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(NbC) often with cobalt like binder (Gelin, 1995). In the case, of standard machining plaques, each composition of carbide takes up all the volume of the plaque.

PROBLEMS

The development of the plaques by injection or insertion of carbide divides up all the volume of the plaque into penetrating parts or sharp and partly supports. Thus a rationalization of the volume of the plaque can be considered. Then, material of cut, carbides for example, is inserted or injected in the cutting or sharp parts. The other parts will receive compatible materials support (heat-resisting steel alloys or other alloys) (Bouchelaghem, 2006).

In the processes of machining by stock removal, at the point of contact part-tool, we can find dynamic and thermal heads. They obviously act on materials in contact. On this level, there is a combination of efforts known as cutting pressures, which can be very important and temperatures or temperatures of cut, which can be also very high (Gelin, 1995; Loladze, 1982). These physical phenomena often give a swift work hardening, a surface quality soaked, wears in notch and crater on the level of skin surfaces and of attack of the tools out of carbide. In addition, they are the cause of the chipping of the cut edge, their progressive deformation and even of their rupture (Trent, 1991).

These extreme working conditions determine the requirements imposed on cut materials. The aptitudes of similar materials can be defined by hardness, breaking strength, wear resistance, heat strength and thermal conductivity.

Objectives: The study aims

- To consider the bond which can exist between the quoted physical phenomena of contact listed above.
- To determine areas of the plaques subjected to the strong requests.
- To choose adequate materials in the various areas.

In order to carry out these objectives, it is essential.

- To have data on tungsten carbides or hard alloys and on their machinability (composition, characteristics, cutting pressures, temperatures, etc).
- To treat the requests by finished elements method.
- To apply software calculations.

MODELING OF THE CUTTING EFFORT

We can identify three material actions on the tool (Gelin, 1995; Loladze, 1982) (Fig. 1):

- Tangential effort of the same cut Fc direction of the cutting movement.
- Advance effort of the same F_f direction of the movement in advance,
- Penetration effort F_a of the same direction of cutting depth movement.

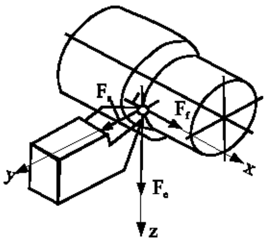

Fig. 1: Diagram of the actions of material on the cutting tool

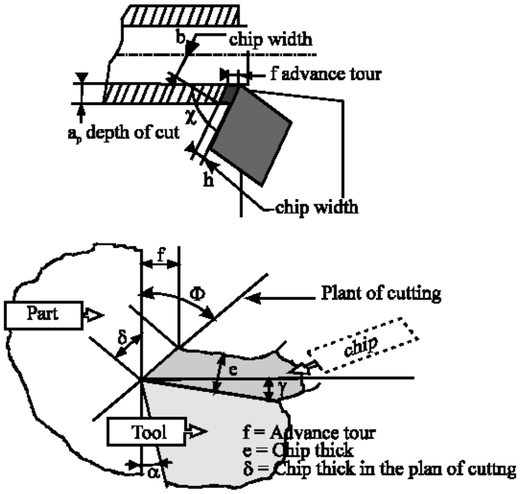

Fig. 2: Diagram of orthogonal continuous cutting

The combination of these efforts gives a resulting power F. In the theory of cut and even according to experimental data, this power F is appreciably equal to the cutting pressure F_C: Effort exerted by the tool on the part. In practice, authors consider this effort to be distributed along two principal directions, one of cut and the other in advance and a third direction defined by the vector product of both directions (Bissey, 2005).

In order to simplify the cut study, we consider the cut known as orthogonal, the study plans of which are defined by the directions of cut. We also take, due to simplification reasons, the angle of direction of edge $\chi = 90°$ and the angle of his slope $\lambda = 0°$. In addition, it is supposed that the cutting speed is constant in any point of the sharp edge in contact with the part.

Under the conditions of the orthogonal cut, represented by the diagrams below (Fig. 2).

The formation of the chip is done according to a plan of shearing whose position (angle Φ) can be given as follows:

$$\left.\begin{array}{l}\delta = \dfrac{f}{\sin\phi} \\ e = \delta.\cos(\phi-\gamma)\end{array}\right\} \Rightarrow e = \frac{f}{\sin\phi}\cos(\phi-\gamma) = f\left[\frac{\cos\gamma}{\tan\phi} - \sin\gamma\right]$$

$$\tan\phi = \frac{f\cos\gamma}{e - f\sin\gamma}$$

Whereas its balance, represented by this diagram (Fig. 3).

Allows the following Eq. to be given

$$\sum\overrightarrow{F_{ext}} = \vec{0} \Rightarrow \int_{S1}\overrightarrow{df} + \int_{S2}\overrightarrow{dn} + \int_{S2}\overrightarrow{dt} = \vec{0}$$

$\int_{S1}\overrightarrow{df}$: General resultant of the torque of the efforts tool/chip.

$\int_{S2}\overrightarrow{dn}$: Normal projection on the plan of cutting of the general resultant of the torque of inter efforts part/chip.

$\int_{S2}\overrightarrow{dt}$: Projection on the cutting plan of the general resultant of the torque of inter efforts part/chip.

S_1 : Contact area tool/chip.

S_2 : Contact area chip/part (S2 in the plan of cutting).

Φ: Angle of friction on S1.

It is supposed that the distributions of contact pressures on the level of S1 and of the normal and tangential constraints on the level of S2 are uniform.

By introducing the shear constraint τ, we can write:

$$\overrightarrow{dt} = t \times ds_2 \times \overrightarrow{t_2} \text{ Þ } \int_{S2}\overrightarrow{dt} = \frac{t \times f \times a_p}{\text{sinf}}\overrightarrow{t_2}$$

So, the graphic static allows us to determine the cutting effort F_C, by projecting

$$\int_{S1} df$$

on the cutting direction and advance effort F_f, by projecting

$$\int_{S1} df$$

on the advance direction (Fig. 4).

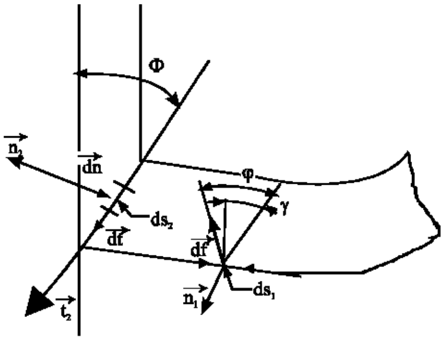

Fig. 3: Diagram of the balance of the chip

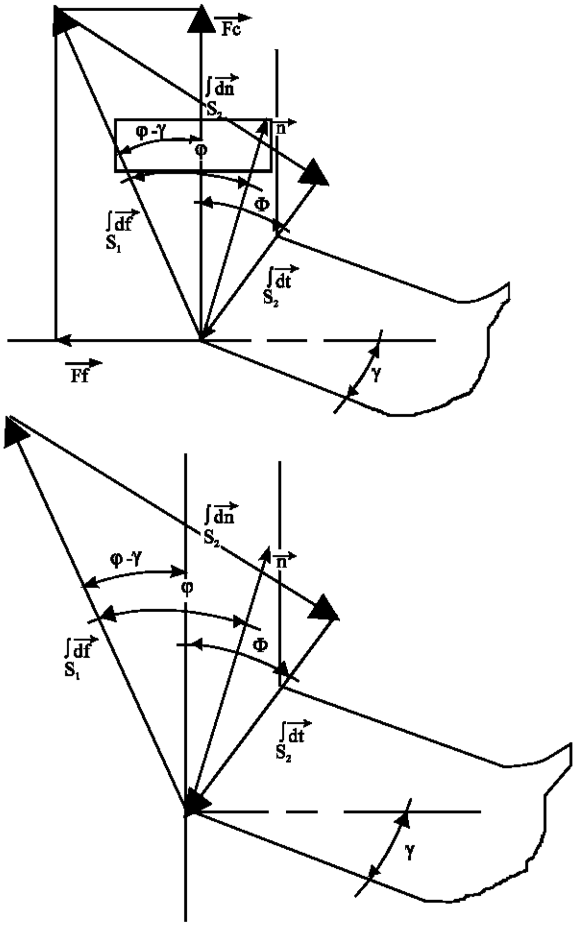

Fig. 4: Diagram of projections of efforts F_c and F_f on the directions of cut and in advance

Determination of F_C:

$$F_c = \int_{S1} df \cdot \cos(\varphi-\gamma)$$

$$\int_{S2} df = \frac{1}{\cos\left[\phi + (\varphi-\gamma)\right]} \times \int_{S2} dt;$$

$$\int_{S1} df = \frac{\tau \cdot f \cdot a_p}{\cos\left[\phi + (\varphi - \gamma)\right]\sin\phi}$$

$$Fc = \frac{\tau \cdot f \cdot a_p \cdot \cos(\varphi - \gamma)}{\cos\left[\phi + (\varphi - \gamma)\right]\sin\phi}$$

By considering the expression

$$\frac{\tau.\cos(\varphi - \gamma)}{\cos\left[\phi + (\varphi - \gamma)\ \right]\sin\phi}$$

as being a specific effort of cut or k_C, i.e. the effort necessary to separate from the part a chip of 1 mm^2 of section

$$k_C = \frac{\tau.\cos(\varphi - \gamma)}{\cos\left[\phi + (\varphi - \gamma)\ \right]\sin\phi}$$

and by admitting that the section of the A_0 chip is the product of the step in advance by the depth of cut, i.e. :

$$A_0 = f\ .\ a_p$$

Thus, it is possible to write a relation of proportionality between the cutting pressure F_C and the section of the A_0 chip as follows $F_C = K_C$. Ao:

Determination of F_f:

$$F_f = \int_{S1} df \cdot \sin(\varphi - \gamma)$$

$$F_f = \frac{t \cdot f \cdot a_p \cdot \sin(\varphi - \gamma)}{\cos\left[\phi + (\varphi - \gamma)\right]\sin\phi}$$

At first approximation and according to experimental data specific to machining of steel and cast iron, with anglesχ = 90° and χ = 45°, the efforts in advance F_f and depth of F_a cut can be determined according to these relations in Table 1.

Whereas the values of k_C according to the matter to be machined and the advance f (Table 2).

Our modeling of the cutting pressure is consequently based on the law of F_C, the reports/ratios of F_a , F_f with F_C and the values of the specific effort of cut k_C.

Table 1: Relations between F_c and F_f , F_a

Tool type	Matter to be machined	F_f	F_a
χ 90°	Steel	2/3 F_c	1/10 F_c
	Cast-iron	2/3 F_c	1/10 F_c
χ = 45°	Steel	2/5 F_c	2/5 F_c
	Cast-iron	1/3 F_c	1/3 F_c

Table 2: Values of specific effort k_c and advance f $F_c = k_c$. A_0

	Specific effort kC (daN mm^{-2})	
Advance f (mm tr^{-1})	Steel	Cast-iron
0,1	320 à 660	190 à 240
0,2	260 à 480	136 à 230
0,4	170 à 350	100 à 170
0,8	124 à 252	72 à 120

To establish the program, in addition to the laws of the modeling of the cutting pressure and in reference to the ISO standard, we introduced the data of a platue to machine type SNUN 120404, out of metal carbide standard P 10 (Norme, 1994) with young modulus E = 6,5.105 and Poisson's ratio ν = 0,3.

TEMPERATURE MODELING

The heat sources (see face) in the process of cut are Loladze (1982):

- The zone of chip formation is the area of the principal mechanical work due to plastic deformation and rupture of metal to be machined. This zone, which includes all the surface of flow, constitutes the first heat source (Q1).
- The friction zone of the chip on the surface of tool attack, with a speed of slip, thus causing a mechanical work, constitutes the second heat source (Q2).
- The friction zone between the skin surface of the tool and the material to be machined with a cutting speed, also generating another mechanical work, is the third heat source (Q3) (Fig. 5).

Heat dissipation caused by all the mechanical work (deformation, rupture, frictions) of the cutting zone is made as follows (Fig. 6).

The quantities of heat to be evacuated by each zone are:

- Q1 = Q1c + Q1p
- Q2 = Q2c + Q2o
- Q3 = Q3o + Q3p

and quantities of heat assessed in each element are :

- Chip: Qc = Q1c + Q2 - Q2o
- Part: Qp = Q1p + Q3 - Q3o
- Cutting tool: Qo = Q2o + Q3o

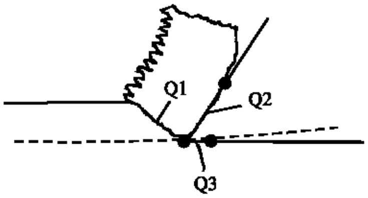

Fig. 5: Diagram of the heat sources in the zone of cut

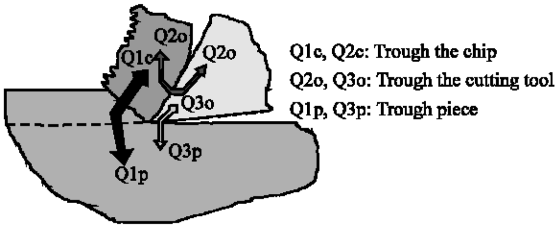

Fig. 6: Diagram of the dissipation of heat in the zone of cut

Now, with the aim of achieving temperatures distribution in the various zones of the cutting plaque, (Habak, 2006) according to the heat source Qo, we chose the expression of the temperature of cut T which takes into consideration the cutting speed and melting points as well as the beginning of heating of the material to be machined:

$$T_C = \left(T_\alpha - T_\beta\right)\ \left(1 - e^{-kv}\right)$$

Where:

T_α : Fusion temperature of the material.
$T\beta$: Temperature of the beginning of heating of the material (piece).
v : Cutting speed (m min^{-1}).
k : Coefficient depending on tangential stress τ_Φ.

$$k = \frac{2,12.10^{-1}}{\tau_\phi} \text{ with } t_\phi = \frac{1}{6}\text{ HV}$$

(HV Vickers hardness of the material). Our modeling of the temperature of cut is based on the explicit TC law which takes account of the cutting speed, functional parameter and of the mechanical and thermal parameters of the material to be machined. Here also and in order to work out the program, the same type of plaque ISO (SNUN 120404, P10) with a thermal conductivity K = 150 W/m. °C and a convection coefficient H = 950 w m^{-2} °C .

The finished element method was used for the analysis and the realization of the grid of the plaque of machining of type SNUN 120404 (Norme, 1994) and software (Castem, 2000) for various calculation applications, software developed by the Mechanical Department and Technology (DMT) of the French Police station with atomic Energy (ECA). The resolution consists of four essential stages:

- Choice of the geometry and the grid.
- Definition of the mathematical model.
- Resolution of the discretized problem.
- Analysis and the postprocessing of the results.

RESULTS AND DISCUSSION

The first results obtained from the approach designed for machining plaque in several sintered showed that the temperature reached 1072°C and the cutting pressures 138 daN/mm^2 at the top of the tool for a standard carbide (79%WC+15%TiC+6%Co) and under normal cutting conditions. Furthermore, this approach enabled us to delimit the thermal request zones as well as effort zones and to deduce under the same cutting conditions (materials to be machined, mode of cut and geometry of plates) that the zones obtained are different in volume. Indeed, the zones of feats are much wider than those of the cutting pressures because heat has the ability of propagation even though the effort is contained and concentrated.

In the case of heat, three zones were delimited:

- Red zone (1/4 of the width of the plaque), the temperature observes between 950°C and 1070°C.
- Green zone (1/4 of the width of the plaque), the temperature observes between 950°C and 850°C.
- Green zone (1/4 of the width of the plaque), the temperature observes between 850°C and 758°C.

Tree zones were delimited with regards the cutting effort, but with of very-reduced-surface proportions:

- Red zone (1/16 of the width of the plaque), the values of the cutting effort lie between 138 and 82.5 daN mm^{-2}.
- Green zone (1/16 of the width of the plaque), the values of the cutting effort lie between 82.5 and 42.7 daN mm^{-2}.
- Red zone (7/8 of the width of the plaque), the values of the cutting effort lie between 42.7 and 10.7 daN mm^{-2} (Fig. 7-10).

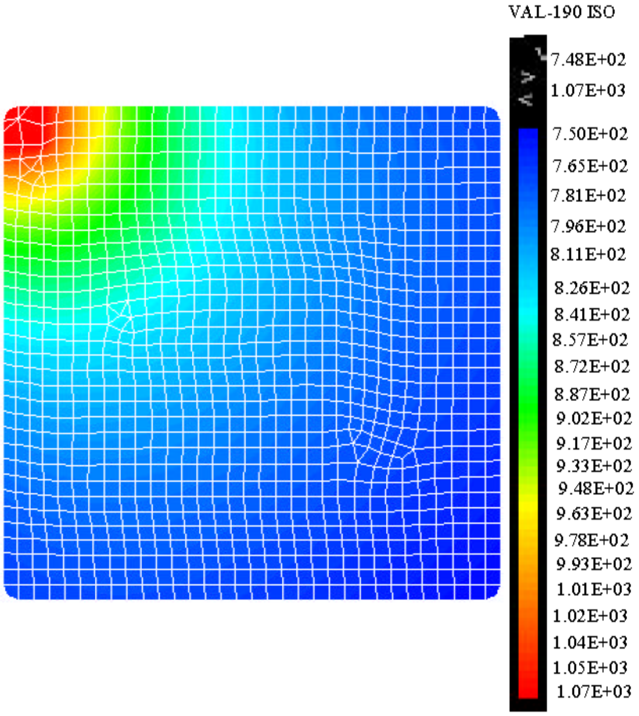

Fig. 7: Computation result of the temperatures and their distribution on the attack area (seen in plan)

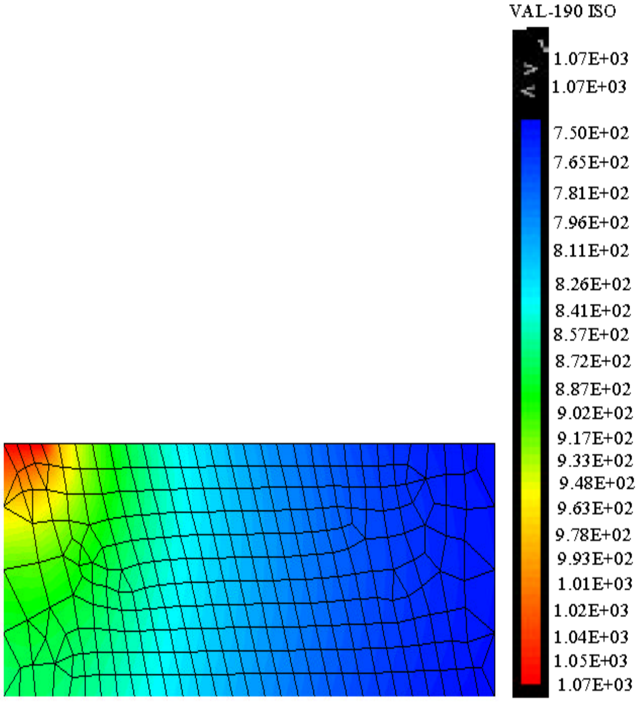

Fig. 8: Computation result of the temperatures and their distribution on the skin area (seen profile)

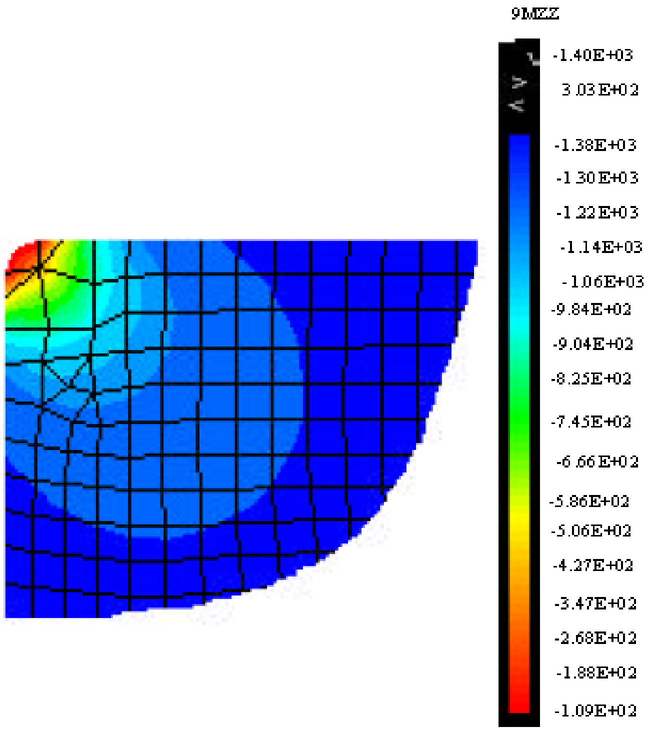

Fig. 9: Computation result of the constraints due to the cutting pressures and their distribution on the attack area (seen in plan)

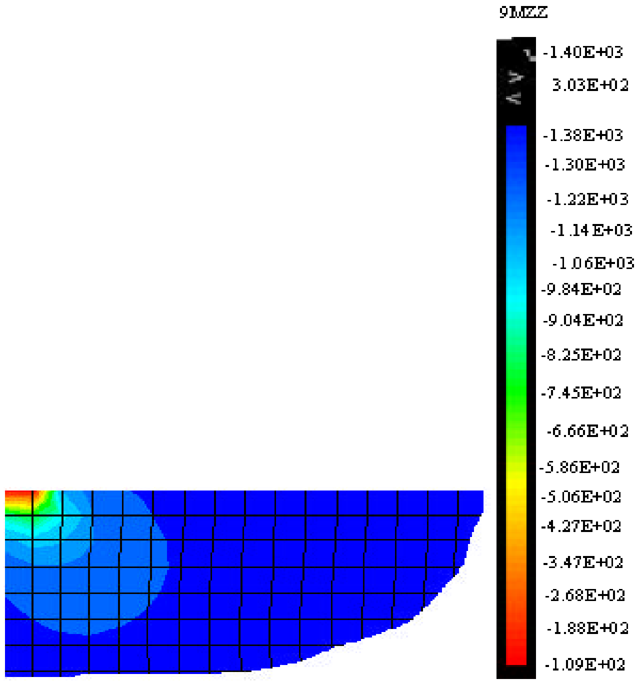

Fig. 10: Computation result of the constraints due to the cutting pressures and their distribution on the skin area (seen profile)

CONCLUSION

These results make it possible to choose the mixtures of carbide powder or other materials sintered to insert in these zones according to these proportions, fulfilling the selected physical parameters (temperature and cutting effort) and the metallurgical requirements of adhesion to the interfaces (common binder or intermediate material).

As an example and for practical reasons, we propose the design of prototypes of plaque while carrying out the insertion of materials, in the zones delimited on the attack surface and extended over all the width of the plaque:

Prototype 1: With two different material zones:

- Zone I or principal zone (equivalent to the red zone in temperature): 60% TiC+10% MoC+30% thermo-resisting steel (14% Ni+14% Cr+10% Mn+6% Co).
- Zone II or auxiliary zone (made up of green and blue zones in temperature): Thermo-resisting steel (14% Ni+14% Cr+10% Mn+6% Co).

Prototype 2: With three different material zones:

- Zone I or principal zone (equivalent to the red zone in temperature): 60% TiC + 10% MoC + 30% thermo-resisting steel (14% Ni +14% Cr +10% Mn +6% Co).
- Zone II or intermediate zone (equivalent to green zone in temperature): 30% TiC + 10% MoC + 60% thermo-resisting steel (14% Ni+14% Cr+10% Mn +6% Co).
- Zone III or secondary zone (equivalent to blue zone in temperature): Thermo-resisting steel (14% Ni +14% Cr +10% Mn +6% Co).

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