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# Numerical modeling of residual stresses in turning of a 27MnCr5 steel

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**Abstract**

Surface residual stresses generated by machining remain a key issue for safety components of mechanical systems. Many simulations technics have been proposed. One of the most promising is to use the hybrid approach, which combines experimental characterizations with numerical computations. The hybrid method simulates equivalent thermomechanical loadings onto the machined surface without modeling the chip removal process. After a preliminary validation of this approach during the machining of an austenitic and a martensitic stainless steel, this papers aims at validating its application on a ferritic-perlitic steel 27MnCr5. This will confirm that the model is capable of predicting residual stresses for a wide variety of alloys.



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Keywords: Residual stresses; turning; 3D numerical modeling; 27MnCr5; surface integrity

## 1. Introduction

Machining and material removal processes in general remain the only way to obtain accurate metallic parts. The dimensional accuracy and the surface roughness are usually easily obtained by manufacturers since they are able to control these parameters on-line. On the contrary, residual stresses is a criteria hardly measurable and understandable by operators. So residual stresses have to be modeled off-line before the cutting operation. However there is currently no click-button software to predict residual stresses. To simulate the residual stresses generation, various strategies were developed by ([1-3]). These methods aim at simulating the cutting process, including the material removal mechanisms (chip formation) which induces long simulation duration and limits the modeling to a single brief cutting operation. On the contrary, in turning, a cutting tool has several revolutions and the surface integrity is a consequence of several passes. In order to overcome this limitation, the hybrid method was developed by ([4-6]). It has been applied successfully on austenitic and martensitic stainless steel and this paper will present its application on a 27MnCr5 steel. This will provide residual stresses profiles for a new steel in order to confirm the model relevance and improve scientist confidence in this approach.

## 2. Hybrid Method

The hybrid method is a numerical method to simulate residual stresses generated by a machining operation which focuses only on thermomechanical loads applied by the material removal process on the final machined surface (figure 1). It has been developed on SYSWELD®. This 'chip less' technic has proven its ability to predict quickly and precisely residuals stress field. It requires an experimental procedure to characterize several input data such as contact length, forces and chip cross section.


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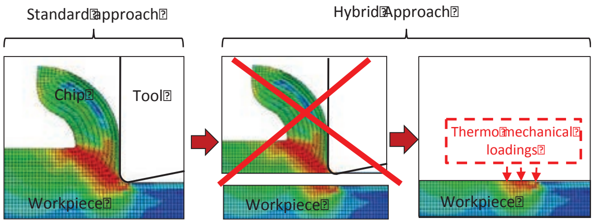


Fig.1: Hybrid method

The shape of the four thermomechnical loadings are detailed in [6].

## 2.1. Experimentations

The experimental campaign begins with a standard turning operation. The cutting tool is a TiN coated tungsten carbide one (TCMW 16 T3 08) . The cutting conditions are the same as the one simulated:

- Cutting speed: 200 m.min$^{-1}$
- Feed: 0.23 mm.rev$^{-1}$
- Depth of cut: 0.5mm

During the machining operation, the cutting forces are recorded with a Kistler dynamometer. After, the contact length and the chip cross section dimensions are measured with a binocular microscope. The picture 2 and 3 present these results.

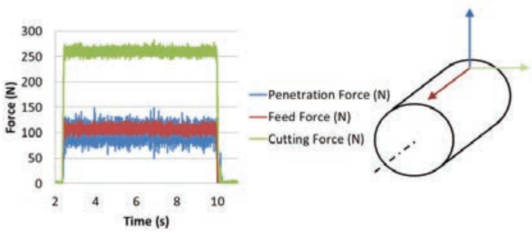


Fig.2: Cutting forces measurments

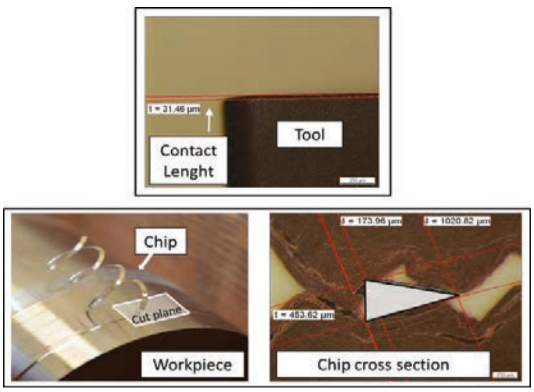


Fig.3: Contact lenghts and chip cross section measurments

The model considers two zones: a direct contact zone and an indirect contact zone. Both are affected by a single cutting pass but in a different way. The width of the direct contact zone corresponds to the feed, whereas the indirect contact zone depends on the depth of cut and on the cutting edge radius. The indirect contact zone will be affected also during the next revolutions (figure 4).

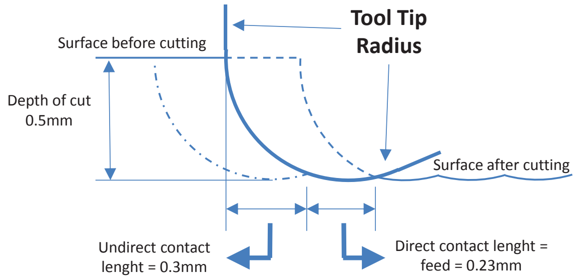


Fig.4: Cutting Sketch (rajouter le rayon de 0,8)

## 2.2. Friction law

The friction law is a key parameter for the hybrid method. In this article the results obtained by [7] were used. The figure 5 presents the evolution of friction coefficient depending on sliding speed. The results were obtained for a TiN coated tungsten carbide pin against a 27 MnCr5 steel.

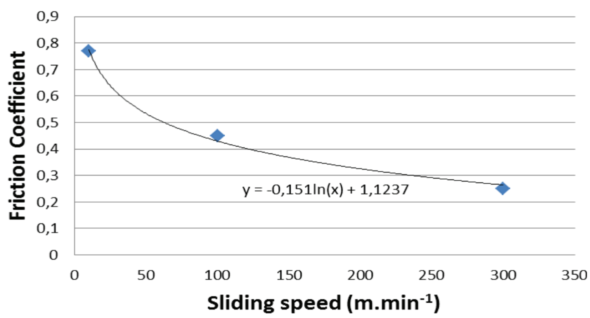


Fig.5: Friction law

## 2.3. Equivalent thermomechanical loads calculation

One of the key step of the method consists in estimating the thermomechanical equivalent loads. Details are presented in [6]. Figure 6 presents the values ready to be applied onto the numerical model surface.

| Input data | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Machining parameters | | | Contact lenghts | | Sketch | | Friction law | | | Machining forces | | |
| Cutting speed ($m.min^{-1}$) | Feed rate ($mm.tr^{-1}$) | Depth of cut (mm) | Chip thickness (mm) | Tool workpiece contact length (mm) | Direct contact zone (mm) | Undirect contact zone (mm) | Chip speed ($m.min^{-1}$) | Tool workpiece friction coefficient | Tool chip friction coefficient | Cutting force (N) | Penetration Force (N) | Feed Force (N) |
| 200 | 0.23 | 0.5 | 0.473 | 0.036 | 0.23 | 0.3 | 128 | 0.26 | 0.31 | 263 | 141 | 100 |

| Calculated data | | | | | |
|---|---|---|---|---|---|
| | | Loads applied to the model | | | |
| Local Cutting Force PSZ (N) | Local Feed Force PSZ (N) | Local Feed Force TSZ (N) | Local Cutting Force TSZ (N) | Heat flow density TSZ ($W.mm^{-2}$) | Heat flow density PSZ ($W.mm^{-2}$) |
| 246 | 77 | 64 | 17 | 2108 | 279 |

Fig.6: Experimental and input data for the simulation

## 3. Numerical model

### *3.1. Model geometry*

As describe in [6], the simulation model consists in a representative parallelepiped with mechanical and thermal boundaries representing an embedded piece of 27MnCr5. The top surface, exchanging with the air has a thermal coefficient of $5.10^{-4}$ $W{\cdot}m^{-2}{\cdot}K^{-1}$ as the other five faces have a coefficient of 0.02 $W{\cdot}m^{-2}{\cdot}K^{-1}$. The meshes are linear quadrangles and their size is progressive with smallest ones near the surface so as not to corrupt the thermal and mechanical gradients at the extreme surface [8] (figure 7).

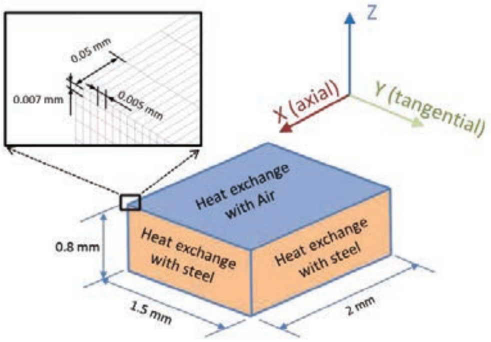


Fig.7: Model geometry and mesh size

### *3.2. 27MnCr5 flow stress model*

The material simulated is a 27MnCr5 annealed with a ferritic-perlitic microstructural structure with a 180HB hardness. As no dedicated flow stress is available, the thermo-mechanical behavior of a this steel was calculated with the work presented in [9]. It is a Johnson Cook formulation with isotropic hardening. (Eq.1)

$$\sigma_{eq} = \left[A + B\varepsilon_{eq}^{\ n}\right].\left[1 + C\ln\left(\frac{\dot{\varepsilon}_{eq}}{0.001}\right)\right].\left[1 - \left(\frac{T - T_{amb}}{T_{fus} - T_{amb}}\right)^{m}\right] \quad 1$$

The table 1 presents the flow stress parameters used to model the annealed 27MnCr5 plastic behavior.

Table 1. Annealed 27MnCr5 Johnson Cook parameters.

| A | B | n | C | $T_{amb}$ | $T_{fus}$ | m |
|---|---|---|---|---|---|---|
| 550 | 585 | 0.33 | 0.013 | 20 | 1460 | 1.1 |

## 4. Results

### *4.1. Experimental Results*

The in depth residual stresses gradients are obtained with an XRD measurement device. These curves are typical residual stress gradient obtained after turning. The extreme surface tensile value is due to high temperature while in depth compression results from extreme mechanical pressure between the tool and the workpiece. The values for 0.3mm depth are assumed to be pre-stress generated while elaboration process of the bars. In fact there is -100MPa of pre stress axial residual stress value and -180MPa for the tangential one.

### *4.2. Numerical Results*

The residual stress distribution is irregular with a period corresponding to the feed rate of the machining operation. To compare the computed results with the experiments, it is necessary to average the numerical values "layer by layer". This method is presented in [6]. Figure 8 presents the comparison between measured and calculated residual stress. Tangential direction corresponds to the cutting direction, while axial direction is collinear to feed. The XRD machine uses a 2 mm collimator so the stresses are averaged onto several pass of the tool. To compare with numerical results, the calculated values are also averaged onto 5 passes of the tool. This value is chosen because it allows to reach the steady state in terms of residual stress generation [6].

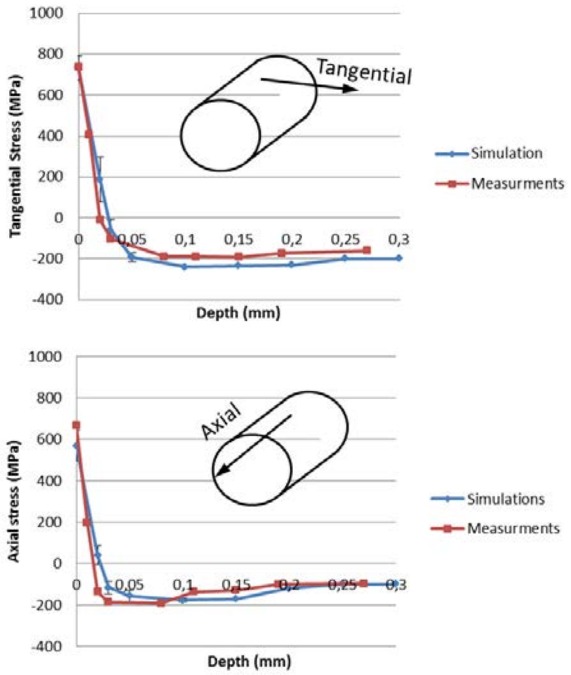

Fig.8 : Comparison between calculated and measured residual stress

## 5. Discussion

The surface residual stresses values (measured and calculated) are very close. It confirms the interest of this approach and the flow stress model has been accurately identified. The in depth values concerning the compressive peek are also well matching. The calculated deepest values are also in good agreement with measurements and it reveals the importance of taking into account prior pre-stress induced by former process for accurate simulations.

## 6. Conclusion

In the past the hybrid method has been successfully applied onto martensitic and austenitic stainless steel and this paper presents its successful application to a ferritic-pearlitic steel. The experimental test consists in a standard longitudinal turning operation in order to identify the input data for the simulation. This step can be conducted within 2 hours. The preparation for the computation is reduced because all the programs are developed and ready to be used. The simulation step realized on SYSWELD® was performed within 5 hours by means of a standard computer. This new application of the hybrid method has shown that it is possible to predict a 3D residual stress field for a new tool/material pair within a single day.

## 7. References

[1] Deng X, Shet C, Residual stresses and strains in orthogonal metal cutting, International Journal of Machine Tool and Technology 43, 2007, P 573–587.

[2] Ee K.C, Finite element modelling of residual stresses in machining induced by cutting a tool with finite edge radius, Journal of Materials Processing Technology 47, 2005, P 1611–1668.

[3] Barge M et al., Numerical modelling of orthogonal cutting influence of numerical parameters, Journal of Materials Processing Technology 164–165, 2005, P 1148–1153.

[4] Mondelin A, Valiorgue F, Rech J, Coret M, and Feulvarch E, Hybrid model for the prediction of residual stresses induced by 15-5PH steel turning, Int. J. Mech. Sci.,58, 2012, P 69–85

[5] Mondelin A, Valiorgue F, Coret M, Feulvarch E, and Rech J, Surface integrity prediction in finish turning of 15-5PH stainless steel, Procedia Eng., 19, 2011, P 270–275

[6] Valiorgue F, Rech J, Hamdi H, Gilles P, Bergheau J.M, 3D modeling of residual stresses induced in finish turning of an AISI304L stainless steel, International Journal of Machine Tools and Manufacture, 53, Issue 1, 2012, P 77–90

[7] Zemzemi F, Bensalem W , Rech J, Dogui A, Kapsa P, New tribometer designed for the characterisation of the friction properties at the tool/chip/workpiece interfaces in machining, Tribotest 14, 2008; P 11–25

[8].A.Cengel,Heattransfert:APracticalApproach,Mc Graw-Hill,ISBN 0070115052, 1998.

[9] Mustapha Abouridouane, Fritz Klocke, Dieter Lung, Oliver Adams, A new 3D multiphase FE model for micro cutting ferritic-pearlitic carbon steels, CIRP Annals Manufacturing Technology, Volume 61, Issue 1, 2012, Pages 71–74