Residual Stresses prediction with a new Thermo Mechanical simulation of Grinding

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ABSTRACT: The grinding process is currently used for most of the parts requiring good precision. However, the apparition of some damage related to this process is still uncontrolled. The major deterioration is from a metallurgical point of view linked to an augmentation of temperature in the workpiece. This paper contributes to understand the way damage appears in ground surfaces performed with grinding. A model for numerical simulation of grinding is presented taking into account both thermal, mechanical and metallurgical aspects.

Key words: Grinding, residual stresses, finite element analysis

1 INTRODUCTION

The grinding process consists of an abrasive contact between a moving workpiece and a wheel in rotation [1]. Because of the grinding power converted into heat at the interface, high temperatures can appear that can lead to thermal, mechanical or metallurgical consequences. Each of these effects has been fully related in literature by authors. Guo presents a good review of surface layers (dark, white layers) in grinding compared with hard turning [2]. On the same idea, Barbacki has shown the effects of grinding not only on microstructure but also on material characteristics [3]. Moreover, it has been demonstrated that there is a relation between nanohardness and the residual stresses of surfaces [4]: generally the nanohardness increases with the compressive stresses and decreases with tensile stresses. Finally few authors have tried to model residual stresses in relation with the grinding power [5]. Nowadays, the main field of interest in grinding is the prediction of residual stresses due to grinding which takes into account not only thermal and mechanical aspects but also metallurgical transformations.

2 GRINDING MODELING

2.1 Global approach

Because of the complexity to model the whole grinding process and particularly the contact between the wheel and the workpiece, an original model has been developed which does not consider the wheel/workpiece contact but only the effects of this abrasive contact on the workpiece. Indeed, at this interface, each wheel grain has a different contact with the workpiece leading to a thermo-mechanical study very difficult to model. On the contrary, a global model of grinding presented in figure 1 is a lot simpler to use.

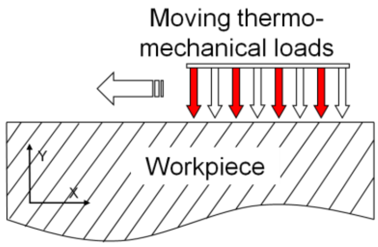

Fig. 1. The global model of grinding

The advantage of this global approach is that it allows simulating more easily the residual stresses induced by grinding. Nevertheless, the major point is to be sure of the values and shapes for the loads models. On that purpose, a method based on experimentations using temperature fields measurements and force acquisitions has been developed and leads to very accurate models [6]. Anyway, the purpose of this article is to present a numerical calculation of residual stresses. Thus, the following part presents the numerical model developed for simulation using simplified loads.

2.2 Numerical model

In previous work, the importance of metallurgy for the apparition of residual stresses on ground surfaces has been shown. The numerical simulation can be a good way to predict them. The key idea of simulation is to build a thermal metallurgical mechanical model and study the influence of phase transformations on the residual stresses.
In order to simplify the simulation, the model is realized in plane grinding. This model which is often used by authors [1,7] consists of a moving heat source on a massive body. Then, because of the stationary of the process, a 2D steady-state model is chosen [8]. In this way, the model is equal to move along the workpiece with the heat source. The advantage of this choice is that we have only one steady-state step of calculation to perform. Nevertheless with this option the length of the model has to be long enough to obtain a good cooling of the workpiece.
The heat flux is assumed to be triangular and the mechanical load is neglected. The total power of the heat flux is chosen at 500W moving at a speed of 150 mm/s and the lubrication is not taken into account. The length of contact is fixed at 10 mm.
Finally a model of 1200 mm length and 50 mm width is meshed with 4-nodes bricks for a total number of nodes around 50000 as shown in figure 2.

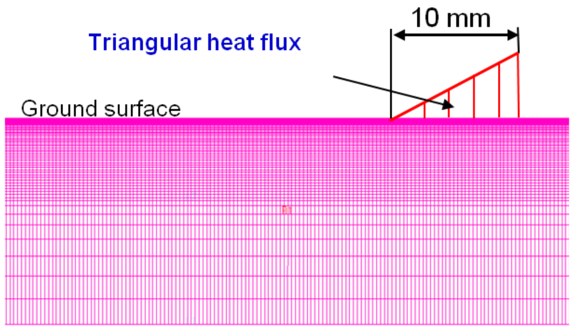

Fig. 2. Mesh and model load.

The computation has been performed with the finite element analysis software SYSWELD® to simulate the phase transformations. The thermal and mechanical calculations are performed successively and detailed in each following parts.

3 NUMERICAL SIMULATIONS

3.1 Thermo-metallurgical simulations

The simulation of metallurgy is performed using the Johnson Melh Avrami's model [8]. With this approach we can simulate the proportion of each phase in relation with temperatures and cooling kinetic. For these first tests, we choose to model only two transformations which are the austenitic and the martensitic ones. The results of this calculation presented figure 3 are firstly the temperature values at the steady state.

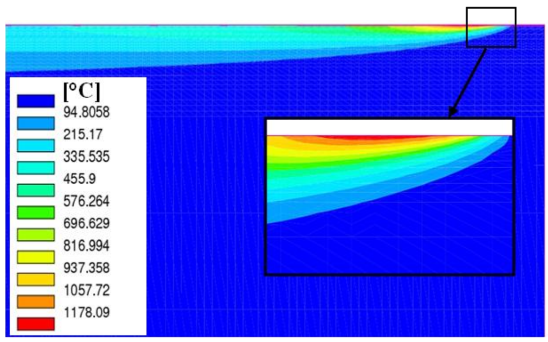

Fig. 3. Temperatures values.

The figure 3 shows that the depth affected is very small and the maximum temperature observed under the heat source reach about 1300°C.
The figure 4 presents the simulated phase evolution when the workpiece finishes its cooling. This simulation shows a martensite transformation at the proximity of the ground surface. This transformation happens only in a small depth of the workpiece in relation with the temperature.

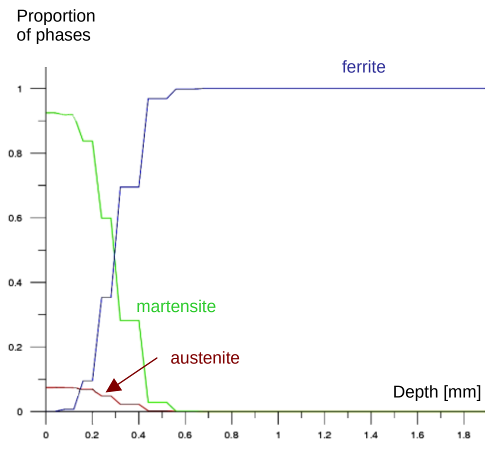

Fig. 4. Simulated proportion of phases.

3.2 Mechanical simulations

There is no mechanical load for this calculation. The only input data are the temperature and phase distribution obtained in the thermal analysis.
Two models have been performed in order to determine the influence of the transformation phases: in the first one the phases characteristics are supposed to be equals. In the second one the characteristics (dilatation, yield stress, hardening slope) are set different for each phase.
The thermal strain is then obtained either with the global expansion coefficient or with the characteristics of each phase. Then, once the thermal strain is obtained, the stress can be calculated through the behaviour of the material. As first approximation the hardening of our material is assumed to be linear, isotropic with a hardening slope of 1000 MPa. The characteristics such as young modulus and expansion coefficient are considered temperature dependents.
First we present the results without taking into account the metallurgical change. To do so, the same characteristics are given to each phase as if no metallurgical transformation happens. The figure 5 presents the curve of the simulated residual stress in the direction of grinding in relation with the depth of the workpiece.

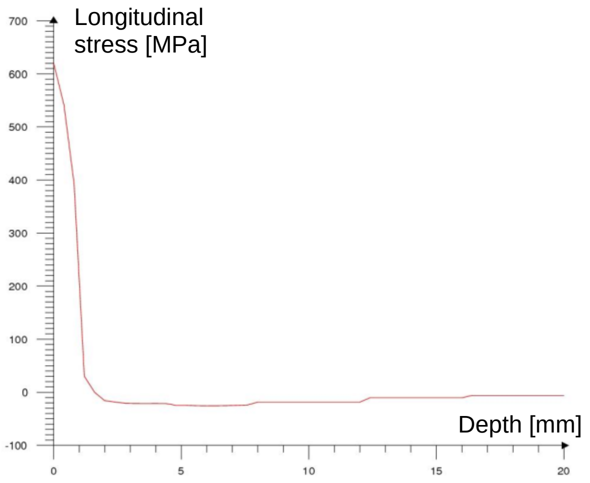

Fig. 5. Distribution of the residual longitudinal stress without metallurgy

These results are in accordance with the theory because only tensile stresses due to dilatation are calculated [9-10].
Then, a second calculation has been performed using different characteristics for each phase. The figure 6 presents the curve of this stress in the depth of the part.

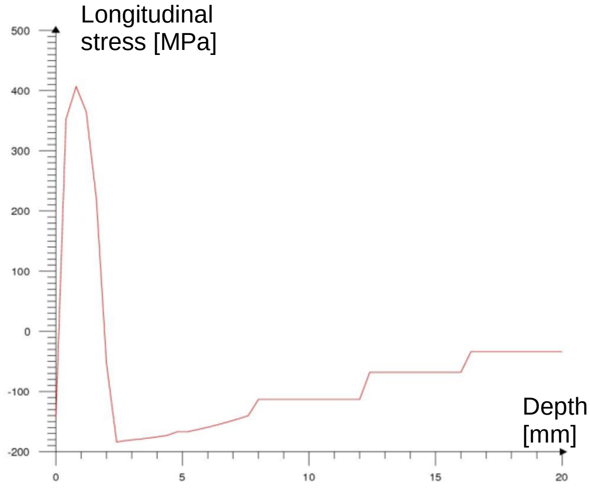

Fig. 6. Distribution of the residual longitudinal stress witht metallurgy (v=150 mm.s^{-1})

The presented numerical simulations give very interesting results which are in agreement with the experiments. With this study we can observe two important phenomena. First, the fact of taking into account the metallurgy leads as expected to compressive stresses on the surface. Secondly, the area of compressive stress is very small and immediately followed by a pick of tensile stress.
It is important to note that the values obtained here can be strongly influenced by the hypothesis chosen. Indeed in this manner the non-lubrication of the

model can be an explanation to the high tensile pick value. Nevertheless the shapes of the curves are in agreement with the theory.
To confirm this thermal metallurgical mechanical simulation an additional test performed with a different speed of the heat flux (50 mm.s-1 instead of 150 mm.s-1) is given with figure 7.

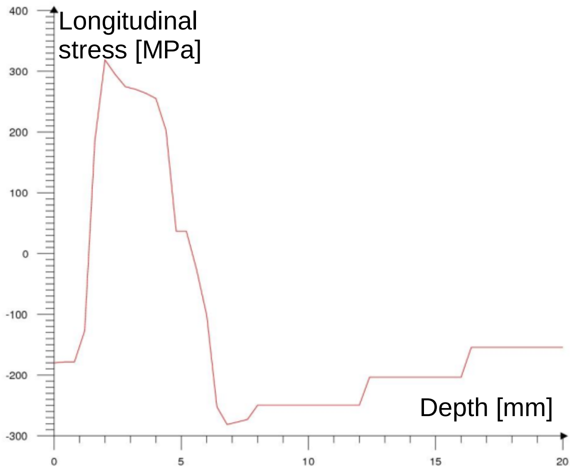

Fig. 7. Distribution of the residual longitudinal stress with metallurgy (v=50 $mm.s^{-1}$)

With a comparison between the figures 6 and 7 one can note that the diminution of the flux speed leads to a decrease of the pick value but also a deeper affected zone. This effect appears correct because it is related to the temperature and validates our numerical model.

4 CONCLUSIONS

The results presented in this paper are very interesting to show the influence of the metallurgy on the grinding process. As predicted in literature the use of model with only dilatation gives tensile stresses which are not always in accordance with the experiments. On the contrary taking into account the simulation of metallurgy leads to compressive stresses.

Finally in this paper it is shown that the grinding process can lead to both tensile and compressive residual stresses. In order to predict them, first simulations using simplified models show us the relevance of numerical simulation.
The next step will be to improve the model with more phases and values and with a model for the lubrication.

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