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Characterisation and modelling of the machinability of ferritic-pearlitic steels in drilling operations

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Abstract

The machinability of work materials strongly affects the chip formation mechanics, tool wear behaviour and the process performance. Therefore, the characterisation and modelling of the machinability are a very important issues. This paper deals with experimental and simulative investigations on the machinability of ferritic-pearlitic steels with different microstructures by twist drilling. The machinability of the investigated steels is evaluated and classified by means of the weighted point evaluation method. To predict four aspects of the machinability (thermo-mechanical load, feed force, cutting torque, and chip form), a 3D FE computation model is developed and successfully validated.

Keywords: FE Modelling; Machinability of FP Steels; Microstructure; Drilling Operations; Constitutive material law.

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1. Introduction

The machinability of a material is one of the most important input parameters for an optimized process design. It determines, apart from the tool wear and the achievable chip removal rates, the surface integrity as well as the functionality of the finished component. The machinability of a material is dependent on the chemical composition and the heat treatment state and thus offers a very wide field in the area of basic research and industrial application [1].

Automotive and engineering industries have to continuously improve the machinability of the most common ferritic-pearlitic steels for a very high machining performance and maximum productivity. So, concerning ferrite-pearlite microstructures, many works exist on improving machinability with optimized inclusion distributions [2-7]. But no study has yet clearly reported the exact contribution of ferrite-pearlite ratio, morphology of the pearlite, interlamellar spacing or even grain size on the machinability. The thermal stress-strain behaviours and the contact mechanisms seem to be not completely understood. Thus, microstructure is usually considered as a global parameter referenced by the present heat treatment condition and microstructural observations are mainly leading to qualitative conclusions [8-10]. The concept of "Integrated Computational Materials Engineering" (ICME) has proved to be successful in practice both for the development of new materials and for the optimisation of machining operations [11]. ICME interlinks the material mechanisms, which proceed during manufacturing on different time and length scales. Therefore, the change in the material properties can be tracked and described numerically during the entire manufacturing chain. On this basis, weaknesses in the production chain and during the service life can be determined and eliminated. Thus, improved component performance can be achieved by tailor-made material microstructure, higher cost-effectiveness in production through computer-assisted process optimization, as well as shortened product development times by means of less trial and error run loops.

The present paper is devoted to the experimental evaluation and the numerical modelling of machinability parameters for drilling ferritic-perlitic steels. The use and validation of innovative ICME tools allows a realistic virtual prediction and real presetting of the machinability of ferritic-perlitic steels based on their microstructure.

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2. Machinability of ferritic-pearlitic steels

2.1. Experimental machinability characterisation

In order to characterise the machinability of the investigated ferritic-pearlitic (FP) steels 27MnCr5 (27R), C45 (45R) and C60 (60R) in drilling, tool life tests were carried out with 8 mm coated carbide drills from Fa. Gühring (Type 5510, Fire-coat: TiAlN/TiN multilayer coating). The drilling tests were conducted with a cutting speed of $v_c = 120$ m/min, a feed of $f = 0.25$ mm/rev, a drilling depth of $t = 3xd = 24$ mm and the application of coolant (10% Emulsion Ecocool TNA 2525 HP, pressure 25 bar). Fig. 1 shows the microstructure of FP-Steels and the drilling test setup. The evaluation parameters of the drilling test results are feed force, cutting torque, chip form, tool flank wear (VB) and the quality of the machined holes.

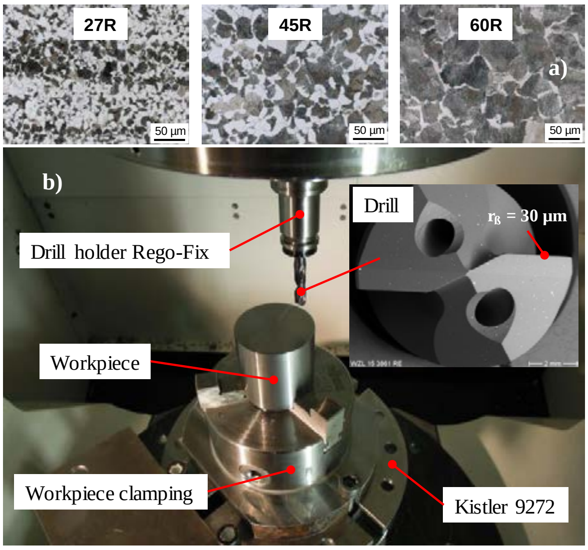

Fig. 1. (a) FP-Steels microstructure; (b) Drilling test setup.

The measured values of feed force and torque during tests scale in a nice manner regarding the carbon content (the fraction of pearlite) of the machined FP-Steels, as illustrated in Fig. 2. The steel 60R shows the highest values of cutting forces.

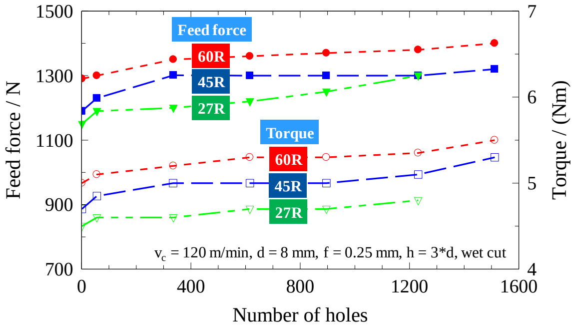

Fig. 2. Feed force and torque over the number of the drilled holes.

The feed force and the cutting torque increase with the number of the drilled holes due to the progressive wear of the used drill. For comparison, the measured values of feed force and torque during dry drilling the first hole with the same cutting parameters are 1300 N, 1380 N, 1400 N and 5.2 Nm, 5.5 Nm, 5.9 Nm for 27R, 45R, 60R respectively. As expected, these values are higher than those determined when wet drilling.

Fig. 3, a) shows the chip form by drilling the FP-Steels 27R, 45R and 60R. Independent of the drilled grade, short chips are detected. A closer look on the machined chips reveals that the chip size decreases a little bit with the fraction of pearlite (from 27R, through 45R to 60R). During the drilling tests, the used carbide drills are analysed regarding the progression of the wear and the dominant wear mechanism. The state of the tool wear on the flank face after the drilling of the last hole in the FP-Steels is plotted in Fig. 3, b). The flank wear on the used drills is uniform along the main cutting edge und no formation of cutting edge breaks could be detected. The measured flank wear correlates well with the content of carbon and is more pronounced by 60R compared to 27R and 45R.

The development of the tool flank wear (VB) over the number of the machined holes is presented in Fig. 3, d). The flank wear increases with the number of the drilled holes. The reached values of the flank wear depend on the acting mechanical load, compare with Fig. 2. To determine the effective wear mechanism during drilling the FP-Steels, SEM examination of the cutting edge after the use is performed, see Fig. 3, c). The wear behavior of the cutting edges is controlled by the wear mechanism abrasion when drilling the FP-Steels. This abrasive wear has led to coat spalling on the cutting edge, as shown in Fig. 3, c).

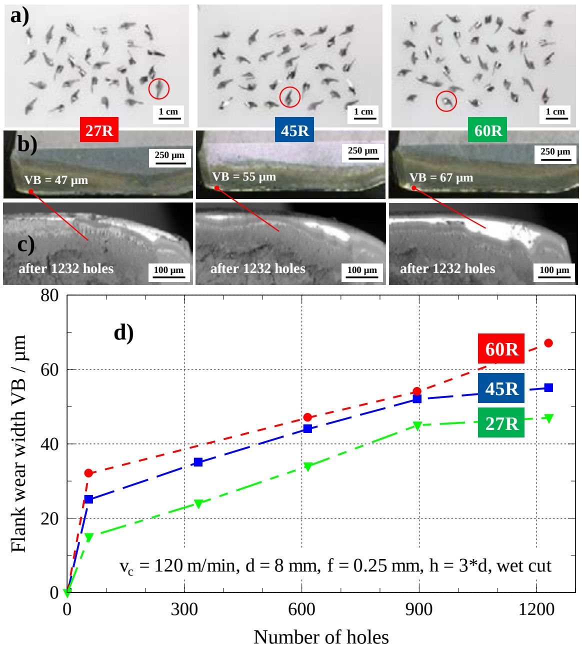

Fig. 3. (a) Chip form; (b), (c), (d) Tool wear when drilling 27R, 45R and 60R.