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Publication date:
2012

Permanent link:
https://doi.org/https://doi.org/10.3929/ethz-a-007560936

Originally published in:
Procedia CIRP 1, https://doi.org/10.1016/j.procir.2012.05.027

Available online at www.sciencedirect.com

SciVerse ScienceDirect

Procedia CIRP 1 (2012) 683 – 684

www.elsevier.com/locate/procedia

5th CIRP Conference on High Performance Cutting 2012

Analysis of the chip formation of bainitic steel in drilling processes

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Abstract

Continuously cooled bainitic steels have the potential to replace conventional quenched and tempered steels in automotive applications. Whereas the machining performance often decides about the cost effectiveness of a particular part, little general knowledge exists about the machinability of such novel steels. First practical experiences with drilling operations confirm the good machinability of bainitic steels as well as the potential for further optimization. Also from a scientific point of view a better understanding of chip formation in the drilling process is desirable. This includes the variation of forces over the drilling edge and the determination of corresponding shear angles. For generating real chip roots a quick stop device was developed. In addition to conventional metallographic micro sections, a non-destructive method namely computer tomography was used for characterization of chip formation based on chip roots.

Keywords: " Drilling; Chip; Steel"

1. Introduction and motivation

Continuously cooled bainitic steels are insufficiently characterized in terms of their machinability, especially in drilling processes. There is a lack of practical knowledge about the material behavior during chip formation. These types of steel combine elevated tensile strength valueswith good ductility. The machinability behavior is supposed to depend on the Charpy toughness level. Comparing with conventional quenched and tempered steels similar or even better machinability is expected. For modeling the drilling process, specific material properties that are relevant for cutting, need to be known. Commercial steel HSX130®HD with a dominant granular bainitic microstructure and a lower bainitic steel 10MnB13 produced by Swiss Steel AG are compared to Q&T steel 51CrV4 [1 – 4].

2. Quick Stop Device

Quick stop chip roots were realized by interrupting the drilling process abruptly through sample release and quick spindle stop. For the experiments, tungsten carbide drills with ⌀4mm and S-Profile reduction of cutting edge were used. By using wire-EDM, the samples of chip roots were cut along well defined working planes.

Table 1. Materials used in experiments

Material	Tensile Strength [N/mm2]	Impact Strength [J]
HSX®130HD (bainitic steel)	980	20
51CrV4QT	1070	80
10MnB13 (lower bainitic steel)	1068	180

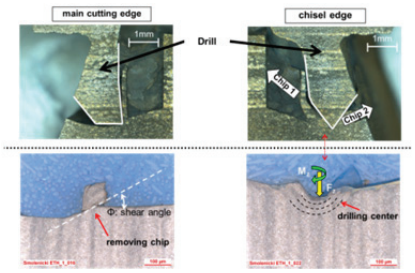

Fig. 1. Characteristic sections, main cutting edge and chisel edge.

2212-8271 http://dx.doi.org/10.1016/j.procir.2012.04.127

Preparation of chip root samples for each position along the tool radius as well as microscopic analysis delivers insight into chip formation during drilling. Fig. 1 shows the difference between main cutting edge and chisel edge. Drill's geometry, especially the rake angle γ and the inclination angle λ are changing as function of radius, therewith also the cutting conditions.

3. Analysis of chip roots

Two methods of analysis were used, non-destructive analysis by Computer-Tomography and the classical metallographic micro sections.

3.1. Non-destructive chip root analysis with Computer-Tomography (CT)

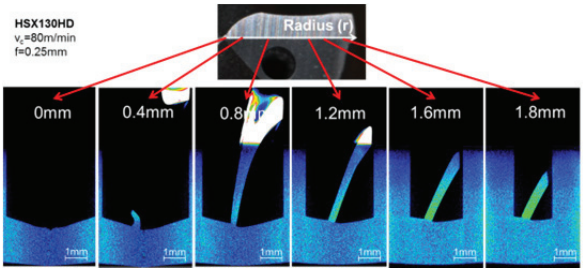

Fig. 2. Different layers form computer-tomography data: chip formation at different tool radius positions, orthogonal to cutting edge

Parameters of the used X-ray source are 140 kV/70µA, no filtration. Pixel size selected - app. 7,3 x 7,3 x 7,3µm.

3.2. 3.2. Metallographic micro sections

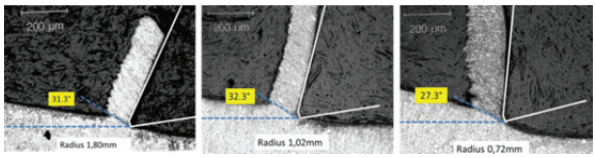

Fig. 3. Different layers from metallographic micro section, chip formation at different tool radius positions, orthogonal to cutting edge

The real chip roots were reconstructed from computer-tomography generated data and given out as .stl-files, which could further be analyzed with CAD-Software. Most interesting information is chip thickness, chip compression ratio λhch and shear angle ϕ as a detailed function of drill tool radius-coordinate. The intersection of a plane with the chip at an orthogonal distance of 0.5mm above the drilling bottom is used, seen as a white contour in Fig. 4.

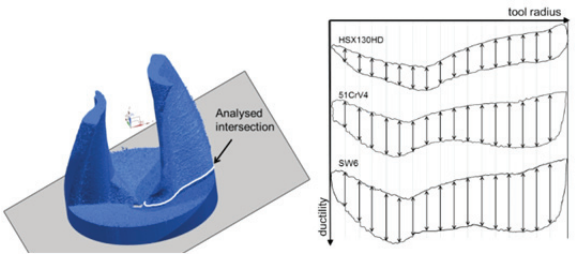

Fig. 4. CAD Model of a drilling quick stop chip, bainitic steel, Drill ⌀4mm, v_c=80 m/min f=0.25 mm; Fig. 5. Chip-cross-sections thickness measured at 16 different positions along the tool radius for 3 materials

Fig. 5 depicts the borderlines of the chip-cross-sections for materials with different ductility but similar tensile strength values (see Table 1).

4. Results

Through development of the Quick Stop device for drilling, chip formation of bainitic steel by drilling edges was visualized. Moreover it provides input for modeling the drilling process and can be used for model validation. Research based on different ductile materials describes the correlation of cutting forces and chip-cross-section to shear planes. With increasing ductility, cutting forces, chip compression ratio and chip thickness get higher in cutting processes. Value of the corresponding shear angle as a function of tool radius-coordinate is dependent on material ductility, tool geometry, cutting parameters and friction. The application of computer-tomography for chip reconstruction has proven to be useful.

Acknowledgements

The authors would like to thank the Commission for Technology and Innovation (CTI) of Switzerland for promoting this research and Swiss Steel AG for providing the bainitic steel materials. Further thanks go to Blaser Swisslube AG and Mikron Tool SA for providing the cutting oils and drills.

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