Continuously cooled bainitic steels with improved machinability

Author(s):
Roelofs, Hans; Lembke, Mirkka; Smolenicki, Darko; Boos, Jens; Kuster, Fredy

Publication Date:
2014

Permanent Link:
https://doi.org/10.3929/ethz-a-010335862 →

Continuously cooled bainitic steels with improved machinability

Hans Roelofs (Swiss Steel), Mirkka Lembke (Steeltec), Darko Smolenicki (IWF, ETH), Jens Boos (Inspire), Fredy Kuster (IWF, ETH)

Bainitic steels as obtained directly from hot-working temperatures by continuously cooling processes can combine high strength levels with good ductility and toughness. For this reason they are attractive alternatives to conventional quench & tempered steels. On the other hand these excellent material properties can make machining very challenging. The optimization of machinability therefore is an essential task to reach economic manufacturing processes with satisfying high productivity. Not only cutting parameters but also steel design has to be considered to reach best results.

Experimental

In the present work three commercial TRIP assisted continuously cooled bainitic steels without (steel B1) and with sulphur addition (steel B2 and B3) are considered in comparison to reference steel 51CrV4Q&T and in comparison to a non-commercial lower bainitic steel grade (LB).

The production routes of the steels were different. The steels were used in following conditions: quench& tempered (51CrV4Q&T); drawn, straightened and stress relieved (B1 and B3) as well as peeled, straightened and stress relieved (B2). Steels B1, B2 and B3 exhibit a cementite-free granular bainitic microstructure with martensite and austenite as second phases. The static tensile properties and the Charpy impact toughness at ambient temperature are given in Table 1.

	Rp0.2 [MPa]	Rm [MPa]	A5 [%]	ISO-V [J]
51CrV4Q&T	**987**	**1069**	**15**	**76**
B1	**673**	**983**	**19**	**20**
B2 (+S)	**852**	**1021**	**17**	**29**
B3 (+S)	**1101**	**1257**	**15**	**19**
LB	**777**	**1069**	**13**	**179**

Table 1 Steel properties

To be able to study the material flow over a wide range of cutting speeds within one experiment drilling was considered to be advantageous over turning. 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. The real chip roots were reconstructed from computer-tomography generated data [5] and given out as .stl-files, which could further be analyzed with CAD-Software. As a result the chip thickness as a detailed function of drill tool radius-coordinate is obtained. Additional turning tests with Ø42 mm bars were performed to investigate chip formation, cutting forces and tool lifetime at defined machining parameters.

Material flow and chip formation

Chip thicknesses were measured after turning tests for all steels. To investigation the influence of steel toughness in more detail quick stop tests were performed with steels B1, 51CrV4Q&T and LB.

The drilling was performed without lubrication at a cutting speed v_c = 80 m/min with feed rate f =0.25 mm/rev. The intersection of a plane with the chip at an orthogonal distance of 0.5mm above the drilling bottom was used to determine the chip thickness, seen as a white contour in Fig. 1.

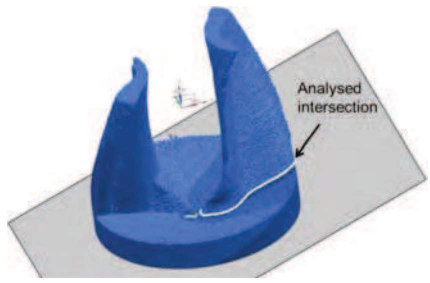

Figure 1 CAD reconstruction of chip root

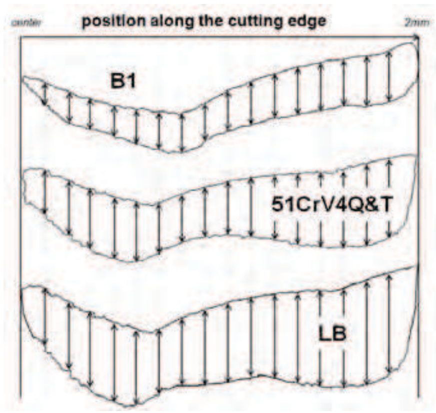

Figure 2 Chip thickness across the Ø4 mm-drilling tool

The resulting values of chip thicknesses across the cutting edge of the drilling tool are shown in Fig. 2. In spite of the slightly lower strength level and the higher elongation at break steel B1 forms the thinnest chips. With increasing Charpy impact toughness the material flow is eased and the chips are clearly getting thicker. This behaviour was confirmed in turning tests with steels B1 and 51CrV4Q&T (cutting depth a_p = 2mm, feed rate f = 0.05 and 0.1 mm/rev, lubrication with

Blasomill B10DM, various cutting speeds). However at higher feed rates (0.15 and 0.2 mm/rev) the difference in chip thicknesses disappeared. Due to the sulphur content steels B2 and B3 exhibit thinner chips leading to lower cutting forces (in average ~10% lower in comparison to steel B1).

Tool wear

In further turning tests the time dependence of cutting force was used to monitor the evolution of tool wear. To accelerate the progress of wear this study was done at an elevated cutting speed of 200 m/min (f= 0.30 mm/rev, a_p = 1 mm, tool PF-4215 with cutting edge radius of 0.4 mm). The test was completed after ~0.3mm of flank wear (VB) or 18 minutes operation time. This procedure is an approved method used by ISF of the TU Dortmund University to test Q&T steels with Rm of ~1'000 MPa.

To analyze the effect of Rm the results of steel B2 (Rm = 1'021MPa) and steel B3 (Rm = 1'257MPa) were chosen for comparison. The time dependences of cutting forces F_c, feed forces F_f and passive forces F_p are shown in Fig. 3 and 4.

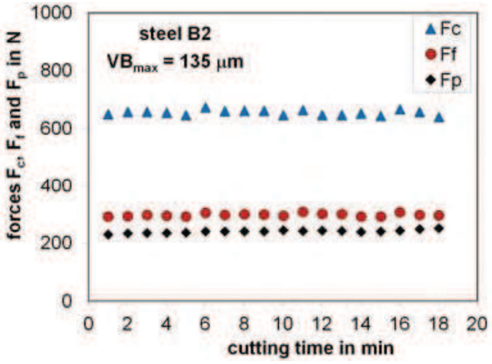

Figure 3 Evolution of F_c, F_f and F_p for steel B2

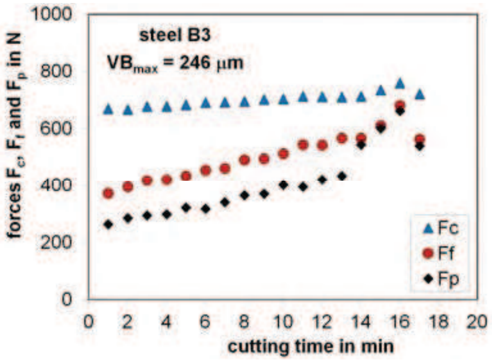

Figure 4 Evolution of F_c, F_f and F_p for steel B3

Higher local stresses or temperature fields must have act on the working tool in case of steel B3. Plastic deformation beneath the cutting edge and spring back effects are under suspect to be responsible for progress in wear. Therefore it was decided to improve the ratio between cutting edge radius and feed rate (v_c=200 m/min, f= 0.25 mm/rev, a_p = 1 mm, tool PF-4205 with cutting edge radius of 0.8 mm) to reduce local stress fields at the vicinity of the cutting edge.

The evolutions of forces for these new conditions are given in Fig. 5 and 6. Both steels successfully passed the 18 minutes cutting time without severe flank wear (B2 with 129µm and B3 with 131 µm). Whereas the cutting forces are comparable for both steels, F_f and F_p were higher for steel B3. This is interpreted as an indication that indeed elastic and plastic deformation forces below the cutting edge are more pronounced in case of harder steel B3.

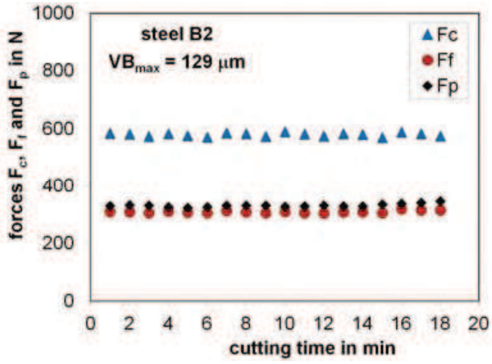

Figure 5 Evolution of F_c, F_f and F_p for steel B2 under improved machining conditions

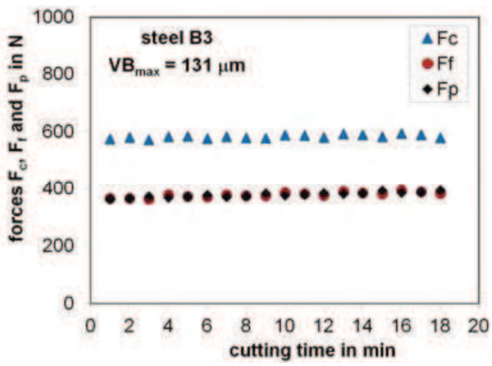

Figure 6 Evolution of F_c, F_f and F_p for steel B3 under improved machining conditions

Choosing appropriate tool geometry the tool lifetime criterion as formulated for Q&T steels with Rm ≈ 1'000MPa could be reached without difficulties. This is true for bainitic steels B1 and B2 as well as for the resulphurized bainitic steel B3 with a ~25% higher strength level.

Acknowledgement

The authors would like to thank Mr. H. Hartmann and Prof. D. Biermann of the Institute of Machining Technology (ISF) at the TU Dortmund University for performing the tool wear investigations and for their general support. The authors would like to express their gratitude to the Swiss Commission for Technology and Innovation (KTI) for financial support in the frame of project KTI 10684.2 PFIW-IW.