Int J Mater Form (2009) Vol. 2 Suppl 1:547–550
DOI 10.1007/s12289-009-0583-9

CUTTING METHOD INFLUENCE ON THE FATIGUE RESISTANCE OF ULTRA-HIGH-STRENGTH STEEL

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ABSTRACT: In this work, the influence of the cutting method on ultra-high-strength (UHS) steels and work hardened austenite stainless steel with regard to static and fatigue stress conditions was studied. In the experimental tests, tensile test bars and fatigue test bars were made using milling and two-laser cutting (CO_2 and Yb:YAG) as well as water jet cutting. The following examinations were performed and related results reported: cutting, measurement of surface roughness, hardness test, micro-structure analyses and the measurement of the heat-effect zone. Specimen strength was tested using a standard tensile test and a fatigue resistance under reversed bending stress test. In the bending fatigue test lowest values were found in the laser cut samples, whereas milled edges gave clearly the best values.

KEYWORDS: laser cutting, water jet cutting, ultra-high-strength steel, austenitic work hardened steel, bending fatigue resistance

1 INTRODUCTION

Many kinds of cutting methods are used in the metal industry. The selection between different methods can be based e.g. on price, tolerance demands or availability. For ultra-high-strength steels, laser cutting is one of the most widely used cutting methods. The advantages of laser cutting are accuracy, speed and flexibility [2]. The laser cut component is frequently ready to assembly as is. The cutting method and edge quality matters when the component is exposed to dynamic stress [1,3]. This is more critical when the component is made of very high strength material.

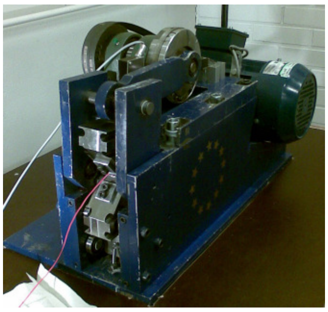

Figure 1. *Bending fatigue test machine*

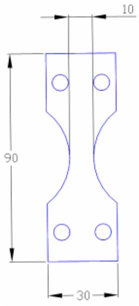

Figure 2. *Fatigue test specimen*

The aim of this study was to determine, using experimental tests, the difference of fatigue properties of mechanically, laser-cut and water jet cut specimens for two complex phase ultra-high-strength steels and three work hardened austenite stainless steels. Fatigue tests are performed using purpose build bending fatigue test machine.

2 TEST MATERIALS

The test materials used were 4 mm thick bainitic-martensitic ultra-high-strength steels CP1100 and CP960 and work hardened austenitic stainless steels 1.4318 2H+C850 and 2H+C1000 in thickness 3 mm and 1.4404 2H+C700 in thickness 3.2 mm. The test material properties are in Table 1.

Table 1. *Test material characteristic*

Material	Thick-ness [mm]	Yield Strength [N/mm^2]	Tensile Strength [N/mm^2]	Elon-gation A_5%
CP960	4	960	1000	7
CP1100	4	1100	1250	6
1.4318 C850	3	530	850	35
1.4318 C1000	3	750	1000	10
1.4404 C700	3.2	350	700	35

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3 EXPERIMENTAL METHODS

Tested cutting methods were machining (MA), water jet cutting (WJ) and laser cutting with two different lasers (CO_2 and Yb:YAG). The CO_2 laser device used was the 4 kW Trumpf 3040L, and the Yb:YAG laser device was a 4 kW Trumpf HLD4002 diode pumped disk. The tensile tests were performed with the Zwick Z100 tensile testing machine, fatigue tests on stainless steels with the Carl Shenck 3-mkp-Wechselbiegemaschine PWO and, on CP-steels [5], with a purpose-built bending fatigue test machine (Figure 1) [6]. The bending fatigue test specimen is in Figure 2. In total, 94 bending fatigue tests were completed. One test was carried out for each stress amplitude, material and cutting method. Surface roughness (Mitutoyo SJ-201P) was measured on some cut edges. Part of the laser-cut edges was examined under a microscope, the purpose being to find some heat changes in the microstructure. Also, Vickers hardness was measured from some specimen near cut edge and base material. Since the target was to find some differences between cutting methods, only the test bars' burred edges were finished.

4 RESULTS AND DISCUSSION

4.1 SURFACE ROUGHNESS

Surface roughness was measured from two pieces of every specimen. Water jet cutting results are worse because measuring can only be performed from a straight surface, and the surface quality was clearly better on the curved test area. The Yb:YAG laser provided the next roughest surface. Machining gave the best quality to stainless steels but CP960 and CP1100 had approximately the same R_a-value when machined or cut with a CO_2 laser (Figure 3). Materials were cut to the rolling direction (RD 0) as well as perpendicular to it (RD 90). On the grounds of the measured R_a-values, it appears that surface roughness is better when the material is laser cut parallel to the rolling direction.

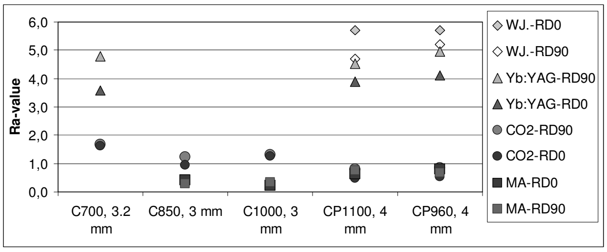

Figure 3. *Surface roughness on the cut edge.*

4.2 TENSILE TESTS

Tensile test results are in Table 1. The results are relative to the machined test bars, so that a positive value means more and negative less strength in comparison to the machined test bar. During the complex phase steel results, the deviation of the results was quite large, as the difference to the machining was also large. CO_2 cut CP 1100 has 10% more yield strength, but only 0.6% tensile strength longitudinally. In the Yb:YAG cut specimens, YS was 6.6% larger than the machined specimens. In the work hardened stainless steels, CO_2-cut specimens' maximum difference to the machined specimens with regard to yield strength (YS) was 2.8%, and in tensile strength (TS) 0.8%. In the Yb-YAG cut specimens, YS was 2.5% and TS was 2.1% weaker. In the tested work hardened stainless steels, the deviation in tensile test results was very small.

Table 1. *Tensile test results, difference to machining*

		Longitudinally RD0		Transversely RD90	
Material	Cutting method	YS%	TS%	YS%	TS%
CP1100	Yb:YAG	+6.6	-3.3	-2.7	-1.0
	CO_2	+10.2	-0.7	+0.6	+2.5
CP960	Yb:YAG	+3.5	-0.0	+5.0	+0.9
	CO_2	+5.0	+1.8	+2.7	+1.2
C1000	CO_2	-1.6	-0.4	-1.8	-0.9
C850	CO_2	-2.8	+0.1	-2.0	+1.3
C700	Yb:YAG	-0.8	-1.5	-2.0	+1.3

4.3 BENDING FATIGUE TESTS

Bending fatigue tests were performed with a purpose-built machine. A strain gauge was glued to every test bar. Four or five different deflexions were used. The largest deflection gave approximately 800 MPa stress: deflection was lowered until the specimen endured at least 2 000 000 stress cycles. The results are presented in Figures 2–5.

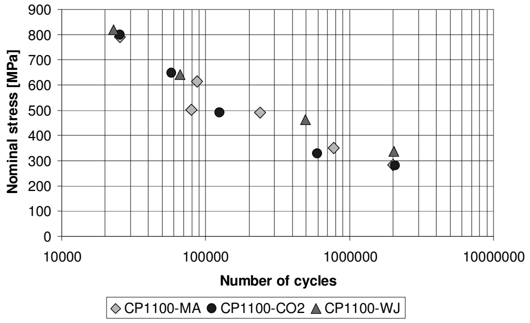

Figure 4. *Bending fatigue test result, CP1100 RD0˚.*

There are bending fatigue test results from material CP1100 in Figure 4,. The results show that in high stress amplitudes, the difference between cutting methods is small and becomes larger in the lower stress amplitudes. A similar situation is noted with CP960 material in Figure 5. Both CP1100 and CP960 laser cut specimens show the worst reversed fatigue strength and water jet cutting best.

In Figure 6, the bending fatigue test results of material 1.4318 C1000 are shown. Similarly to the complex phase materials, the differences between milling and laser cutting in high stress amplitudes were minimal and become larger at smaller stress amplitudes.

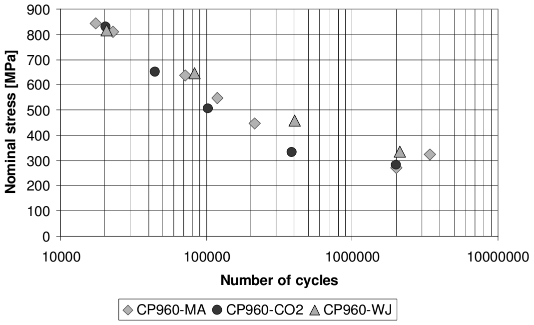

Figure 5. *Bending fatigue test result, CP960 RD0˚.*

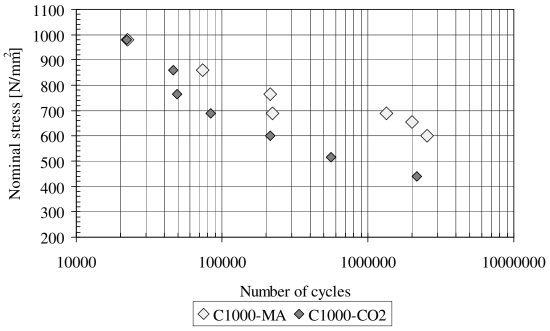

Figure 6. *Fatigue test result, 1.4318 C1000 RD 90˚.*

The test results from material 1.4318 C850 are shown in Figure 7. The test material reversed fatigue strength is more favourable in the transversely of rolling direction. At lower stress amplitudes, the difference between milling and laser cutting is larger than in high amplitudes.

The 1.4404 C700 material was cut using the Yb:YAG laser. In the bending fatigue tests, the specimens were 45 - 62% weaker than specimens made using milling.

The CP1100 and CP960 fracture surfaces were similar. The machined CP960 fracture surfaces are shown in Figure 8. In the machined and water jet cut specimens, the fracture initiation point location varies and the fracture surface looks the same. In the laser cut specimen, the fracture initiation point was predominantly near the corner in the HAZ area (Figure 9). In the work hardened austenite stainless steel fracture, the surface of the machined specimens (Figure 11) had more initiation points, and the geometry was rougher than with the laser cut fracture surface (Figure 9).

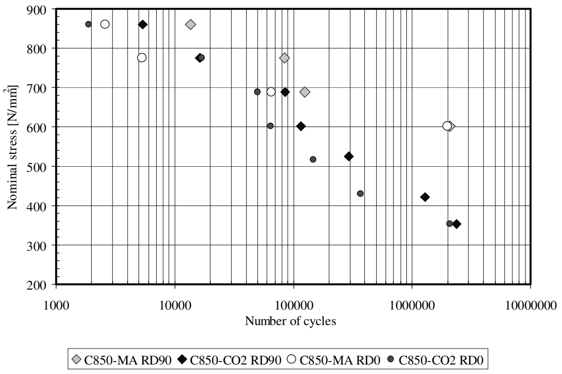

Figure 7. *Fatigue test, 1.3418 C850 RD 90 and RD0˚.*

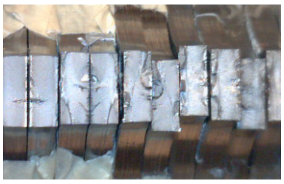

Figure 8. *CP960 machined*

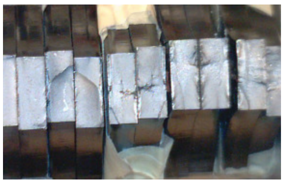

Figure 9. *CP960 CO_2 cut*

Figure 10. *C850 machined*

Figure 11. *C850 CO_2 cut*

4.4 MICROSTRUCTURE AND HARDNESS

From the microscope analysis, the width of the heat effect zone (HAZ) of CP960 was from 170 (Figure 12, Yb:YAG) to 82 µm (CO_2). The CP1100 HAZ widths were 141 µm in Yb:YAG and 92 µm in CO_2. In the microstructure picture, there is a wide hardened zone with smaller grain size than with the base material, and a very narrow annealed zone in the HAZ area. On the basis of the hardness test, the HAZ hardened zone was 8 - 15% harder than that of the base material (Table 2.). In the work hardened austenite stainless steels, the HAZ area width was 100 - 168 µm (Figure 13). The HAZ area was annealed, and its hardness was 21 - 23% less than the base material (Table 2.).

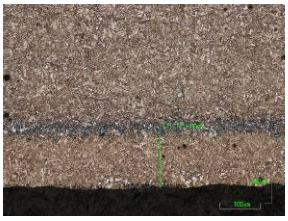

Figure 12. *CP960 Yb:YAG*

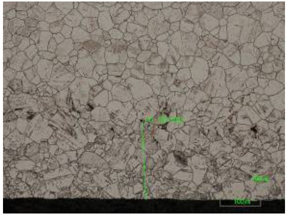

Figure 13. *C850 CO_2 cut*

Table 2. *Hardness test results*

Material		Base [HV0.1]	60µm [HV0.1]	Change [%]
CP1100	Yb:YAG	409	469	15
CP960	CO_2	357	400	12
CP960	Yb:YAG	371	389	5
C700	CO_2	314	243	-23
C700	Yb:YAG	290	226	-22
C850	CO_2	343	271	-21

5 CONCLUSIONS

The present paper describes the results of the cutting method influence on the fatigue strength of ultra-high-strength steel. The tested bainitic-martensitic complex phase steels CP960 and CP1100 were cut using milling, water jet cutting and a CO_2 laser cutting device. In the bending fatigue tests, there were no significant differences between machining and water jet cutting. The reversed bending fatigue strength of the laser cut specimens (CO_2) was clearly weaker (about 40% in 450–650 N/mm^2 stress amplitude) than with the machined specimens although the value of the stress amplitude is still high compared to the standard steels.

With the tested work hardened austenite stainless steels 1.4318 C850 and C1000, the reversed fatigue strength of the CO_2 cut specimens was also clearly weaker (~62% in 650–750 N/mm^2 stress amplitude) than the machined specimens. The result was similar in the cut respective to the 1.4404 C700 material using the Yb:YAG laser. Here as well the stress amplitude remains on a high level compared to the standard stainless steels.

In order to find the complete form of the fatigue curve more tests should be carried out especially with greater number of cycles. The influence of surface roughness requires also further experimenting as the thermally cut edge can be a crucial part of a dynamically loaded structure.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the financial support received from TEKES for the ‘ULLE’ project and the State Provincial Office of Oulu, as well as from the European Union (European Regional Development Fund) in support of the ‘INTO’ project. The authors would especially like to thank the following companies for their continuous and profound support during the project: Rautaruukki Oyj – Ruukki Metals, Outokumpu Stainless and HT Lasertekniikka Oy.

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