INFLUENCE OF MATERIAL CUTTING ON THE CYCLIC FATIGUE OF TRIP STEEL

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Abstract

Formed parts of the car-body represent cyclic loaded products. For the proper design of these parts is very important not only knowledge of deformation and stress material behaviour at production by forming technologies but important is also knowledge of other factors which influence subsequent product utility properties at the car operation. It´s obvious that truly important parameter for the proper car-body part proposal is the fatigue strength of the given material. Mainly for cyclic exposed stampings of chassis assembly is knowledge of used materials fatigue strength one of the basic presumptions for the safe car operation. Measured dependences of stress size on the number of cycles (Wöhler´s curves) are thus very important input parameter at design for the given car-body part. However from the practical point-of-view they don´t reflect influence of individual production technologies on the fatigue strength of processed materials. Regarding fact that formed parts from steel sheets are during production cut by several different technologies is submitted paper focuses on the determination of material cutting influence on the fatigue strength. For experiment there was chosen ultra-high strength TRIP steel and the most commonly used material cutting technologies (laser cutting, shearing and machining). For samples prepared as mentioned was on the six stress levels observed material cutting influence on the achieve number of cycles up to fracture. Results of experiments were compared with the reference samples which were machined. Results from measurements are presented mainly graphically as stress versus number of cycles and fatigue fracture surfaces images from the electron microscope.

Keywords: Wöhler Curve, Ultra-high Strength Material, Cyclic Fatigue, Material Cutting

1. INTRODUCTION

These days are especially car producers forced to process still more and more types of materials with high strength (mainly high-strength steels). This phenomenon arises from increasing demands for higher passive safety and for the lower weight of cars at the same time. These contending claims can be fulfilled just by application the higher amount of ultra-high strength materials at the car-body design [1]. This application of ultra-high strength materials means also production technologic problems among them can be found also preparation of workpiece. This is also very important reason that nowadays are more and more used also non-conventional cutting technologies - mainly laser cutting, eventually plasma cutting or water jet cutting. Regarding the fact that because of economic reasons are no cut edges being machined after cutting, used cutting method and its character has a very important influence on the subsequent work piece plastic properties [2]. That is why this paper deals with the influence of cutting technologies on the cyclic fatigue of so-called TRIP steel (structure - **Fig. 1**) cause this steel is able to reveal strengthening during impact and thus to absorb part of impact energy.

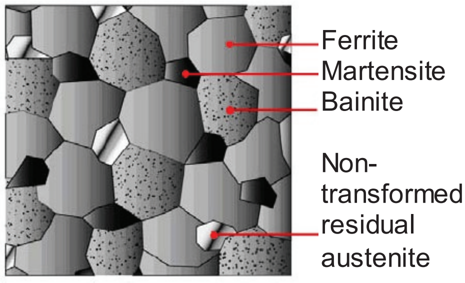


Fig. 1 Structure of TRIP steel

2. METHODOLOGICAL BASE AND EXPERIMENTAL PART

For testing influence of material cutting on the cyclic fatigue was chosen TRIP steel RA-K 40/70 which is used in the automotive industry mainly for production reinforcements and car-body chassis parts. In the experimental part were firstly carried out tensile tests for 3 directions regarding the rolling direction (0 °, 45 ° and 90 °).Then there were carried out fatigue tests (determination of Wöhler´s curves) for samples prepared by different cutting technologies and images of fatigue fracture surfaces from the electron microscope.

2.1. Static tensile test

The static tensile test is basic test for determination material mechanical properties and enables to get information about deformation abilities of the tested material. In **Table 1** are summarized measured mechanical properties for TRIP steel 40/70 for directions 0 °, 45 ° and 90 ° regarding the rolling direction. Graphical illustration of measured results from the static tensile test is shown in **Fig. 2**.

Table 1 Mechanical properties of the tested material (TRIP steel RA-K 40/70, thickness 1.5 mm)

Rolling dirrection	**Yield strength** R_e [MPa]	**Ultimate strength** R_m [MPa]	**Uniform ductility** A_g [%]	**Total ductility** A_{50mm} [%]	**Strength coefficient** C [MPa]	**Strain-hardening exponent** n [1]	**Normal anisotropy coefficient** r [1]
0 °	459.2	760.8	20.7	27.8	1423.1	0.2589	0.7843
45 °	462.1	763.7	22.9	29.1	1421.4	0.2611	0.7317
90 °	461.7	762.4	23.2	28.8	1433.5	0.2653	0.9148

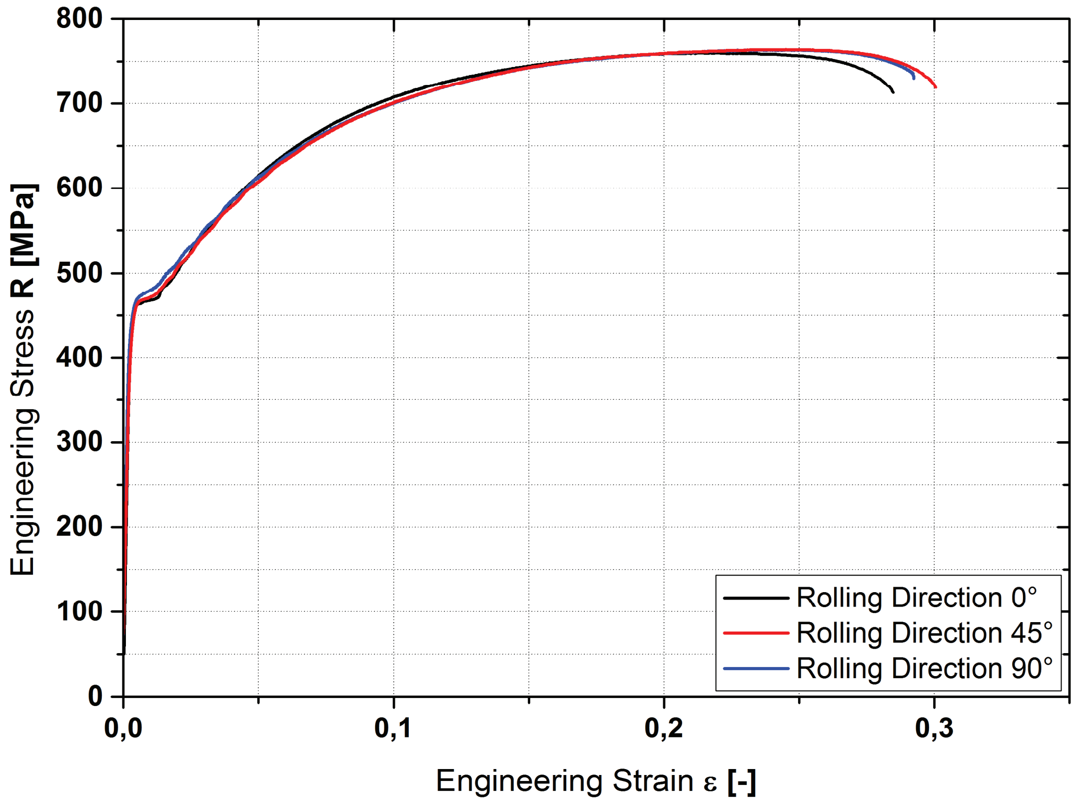
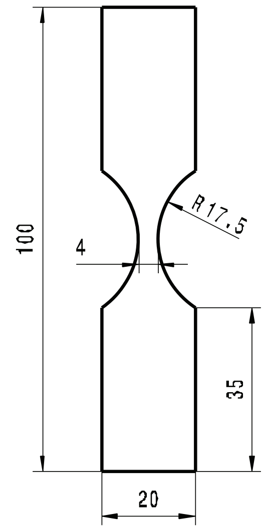


Fig. 2 Results from the static tensile test - material: RA-K 40/70

2.2. Preparation of samples for the cyclic test

To determinate influence of material cutting method on the cyclic fatigue there were firstly prepared samples by following cutting technologies: laser cutting, shearing and machining. Shape and dimensions of these testing samples were chosen with respect to the subsequent cyclic tests which were carried out by the machine Instron E3000. Its maximal force for tests was 3 kN. Entire preparation of samples was done in cooperation with Centre for Nanomaterials, Advanced Technologies and Innovation TU of Liberec where are all technologies for material cutting mentioned above at disposal. Shape and dimensions of testing sample are shown in **Fig. 3** (left). At laser cutting there were used laser head from company Laser Mechanisms, load of laser 400 W, feed rate 500 mm·min^{-1}. Lay-out of this workplace is shown in **Fig. 3** (right).



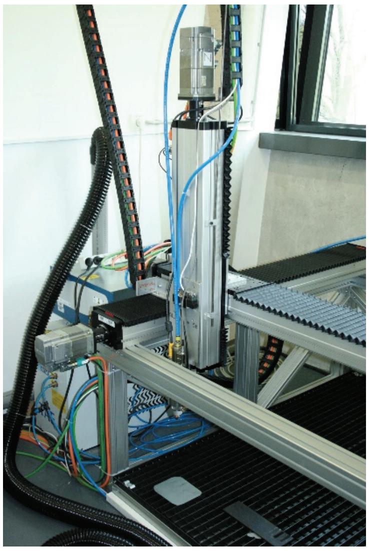
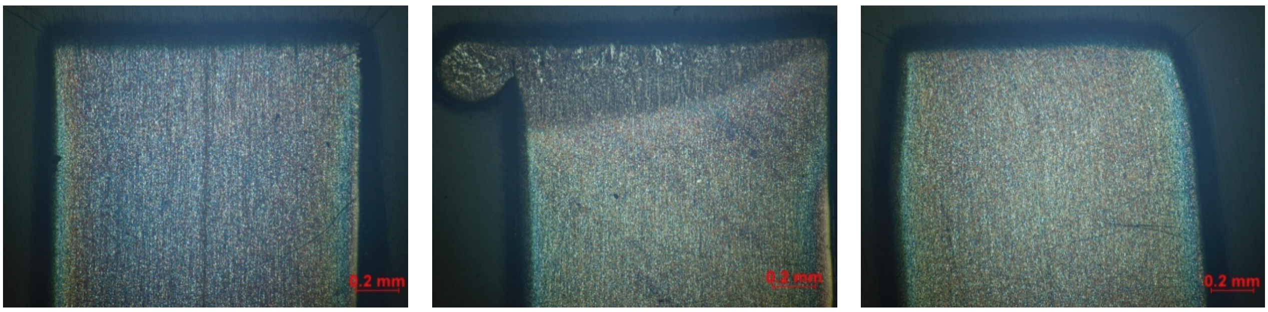


Fig. 3 Shape and dimensions of testing sample (left) and lay-out of the whole laser cutting workplace (right)

Samples prepared by machining were milled by the shank cutter with diameter 35 mm. During preparation of samples by shearing there was used cutting clearance with 5 % of the sheet thickness. Achieved testing samples cut edges quality can be seen in **Fig. 4**, where are shown images from the optical microscope NEOPHOT 21 of metallographic scratch-patterns.



a) b) c)

Fig. 4 Shapes of cut edges for milling (a), laser cutting (b), shearing (c).

2.3. Cyclic tests

Cyclic life curves σ_a-N_f (Wöhler´s S-N curves) give information about dependence of the cycles to failure N_f on the fatigue stress in terms of stress amplitude σ_a. Wöhler´s curve can be generally plotted for several mean stresses σ_m, which influence its course. Usually there are experimentally determined two Wöhler´s curves namely at the symmetrical loading cycle ($\sigma_m = 0$) and at the transient loading cycle ($\sigma_m = \sigma_a$). For both diagrams there is common decrease of cycles to failure with increasing stress. Such area is called as the time-dependent fatigue strength area and is limited from the right by number of cycles N_C (number of cycles where there is not fatigue fracture above it). Area with the number of cycles $N > N_C$ is called as the permanent fatigue strength area (infinite life) [3]. For the experiment there was chosen transient loading cycle whose course is shown from **Fig. 5** (right). For cyclic testing in the zone of low-cyclic loading where value of applied force gets over 3 kN was used modernized universal test machine TIRAtest 2300 which enables to carry out tests up to frequency 3 Hz. In this case there was used loading frequency of 1 Hz. For the area of high-cyclic loading was used device Instron E3000 which is primary designed for these kinds of tests with possibility to set frequency up to 350 Hz. For this high-cyclic loading there was used loading frequency of 40 Hz. The device for high-cyclic tests Instron E3000 is shown in **Fig. 5** (left) together with detail of gripped sample in the jaws of testing device.

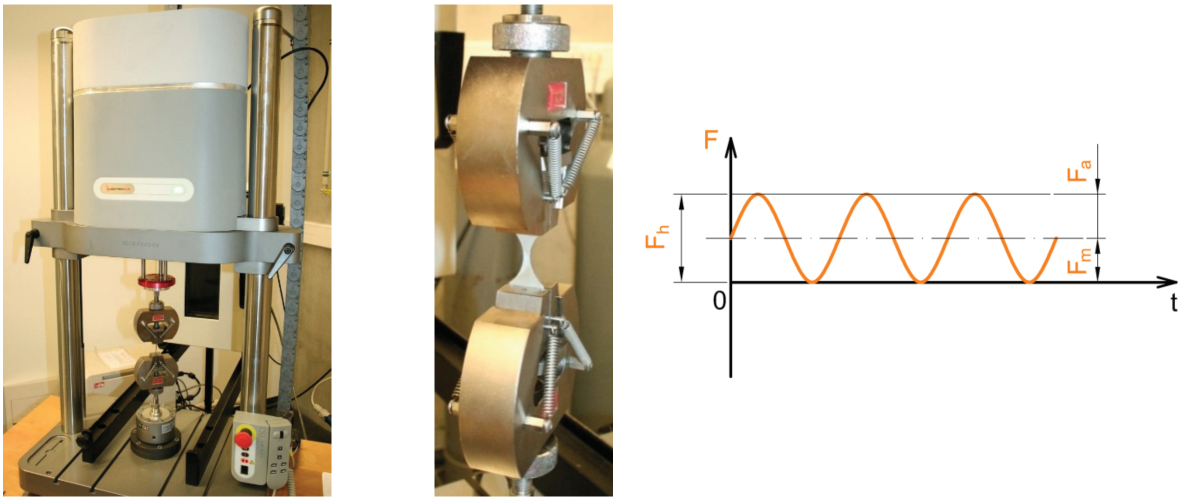


Fig. 5 Machine for cyclic tests Instron E3000 and chosen loading cycle

In the area of the Wöhler´s curve time-dependent fatigue strength were always measured 7 stress levels. To measure relevant results there was for every stress level such measurement 5-times repeated. In final graphs is always written mean value from these 5 measurements. Also in this area of fatigue strength was for the approximation of measured values used the Wöhler-Basquin´s equation:

$$\sigma_a = \sigma_f^{/} \left(2N_f\right)^b \quad (1)$$

where:

σ_a - amplitude of stress [MPa]

$\sigma_f^{/}$ - fatigue strength coefficient [MPa]

b - fatigue strength exponent [-]

As results from carried out experiments there are constants from the approximation mentioned above (1) for all tested cutting technologies (laser cutting, shearing, machining) of RA-K 40/70. Moreover there are graphs illustrating dependence of the amplitude on the cycles to failure (number of cycles). The example how to compute constants of the approximation equation (1) is shown from via graph in **Fig. 6**. There are summarized all important quantities - measured points of the Wöhler´s curve and the approximation curve according (1). Computed constants are summarized in the table which is also shown in **Fig. 6**. This example how to compute important constants is done for the laser cutting technology.

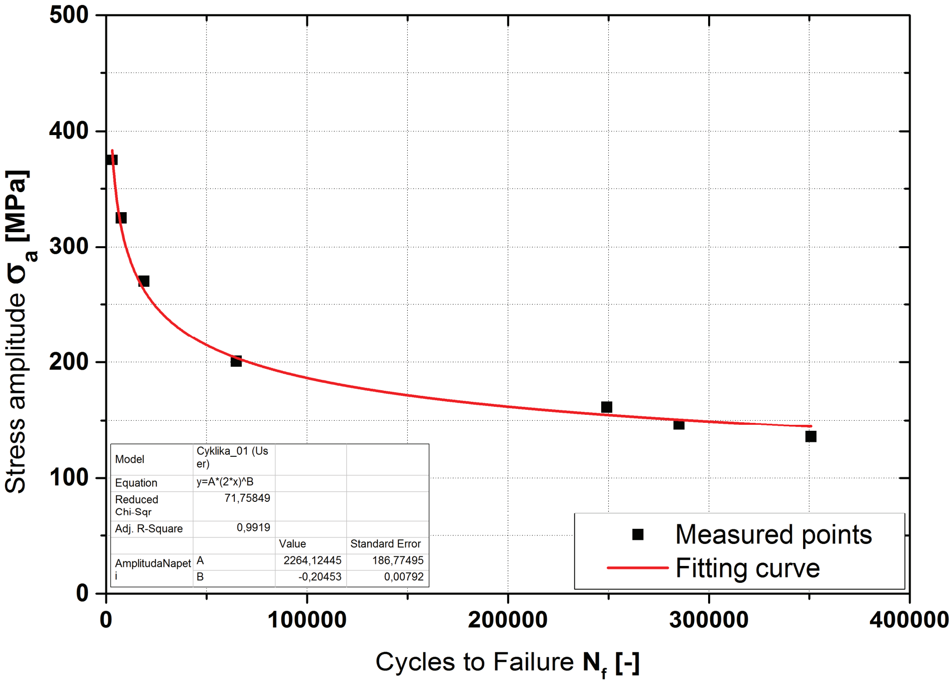
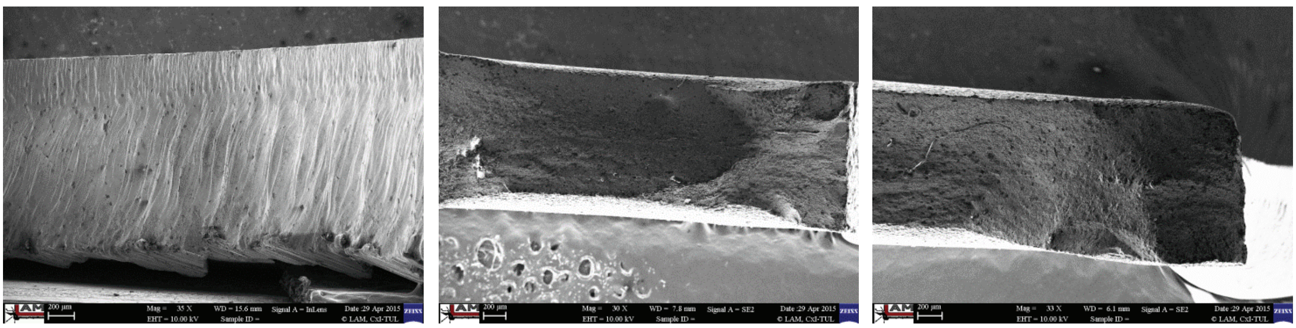


Fig. 6 Example of computation approximation constants for the laser cutting technology

Constants for the Wöhler-Basquin´s equation (1) for all tested material cutting technologies are summarized in **Table 2** where are also shown values of fatigue strength.

Table 2 Results from measurement fatigue tests for material RA-K 40/70 at different cutting technologies

Material cutting technology	Fatigue strength coefficient [MPa] σ_f'	Fatigue strength exponent [-] b	Fatigue strength [MPa] σ_c
Laser cutting	2264	-0.20453	128
Shearing	932	-0.09263	242
Machining	1585	-0.14445	209



Laser cutting Machining Shearing

Fig. 7 Images of fatigue failure surfaces loaded by transient cycle with amplitude of stress 325 MPa

Within the frame of the experimental part there was also carried out research of material fatigue failure by means of images from the electron microscope. Examples of these images for fatigue failure surfaces for samples loaded by transient cycle with maximal loading of 650 MPa are shown in **Fig. 7**.

3. CONCLUSION

These days is majority of personal cars designed as platform of the unitary car-bodies. Such conception has contributed to the significant weight reduction of the whole car while keeping the required rigidity. Car-body as the one complex is designed as a weldment mainly from metal sheet stampings with different properties (different mechanical properties, surface treatments, material thicknesses) which are the most frequently joint by the resistance spot welding (the higher portion), by the MIG/MAG, TIG and laser welding, mechanically by means of screws and nuts, overlap jointing, trimming or these days still more and more by adhesive bonding. That is why in this paper was tested so-called TRIP steel as a member of UHSS (ultra-high strength steels) to evaluate influence of cutting technologies on the fatigue strength. In the previous chapter was described the entire methodology how to compute all important constants for fatigue tests. These results are summarized in **Table 2**. Moreover there were made images of fatigue failure surfaces from the electron microscope - see **Fig. 7**. Graphical illustration of measured values is shown in **Fig. 8** where are plotted Wöhler´s curves of TRIP steel RA-K 40/70 for different material cutting technologies. From this comparison can be concluded that for RA-K 40/70 is the most negative influence from the laser cutting. Further research should be focused on the zones affected by strengthening due to the thermal loading. Also measurement of micro-hardness should be carry out in the zones of cut edges to reveal change of hardness values which strongly influence material mechanical properties. Results from shearing and machining are in light of fatigue cycle testing comparable. Results are truly very important to evaluate influence of cutting methods on the TRIP steel plastic properties. On the other hand, this kind of tests is very time consuming.

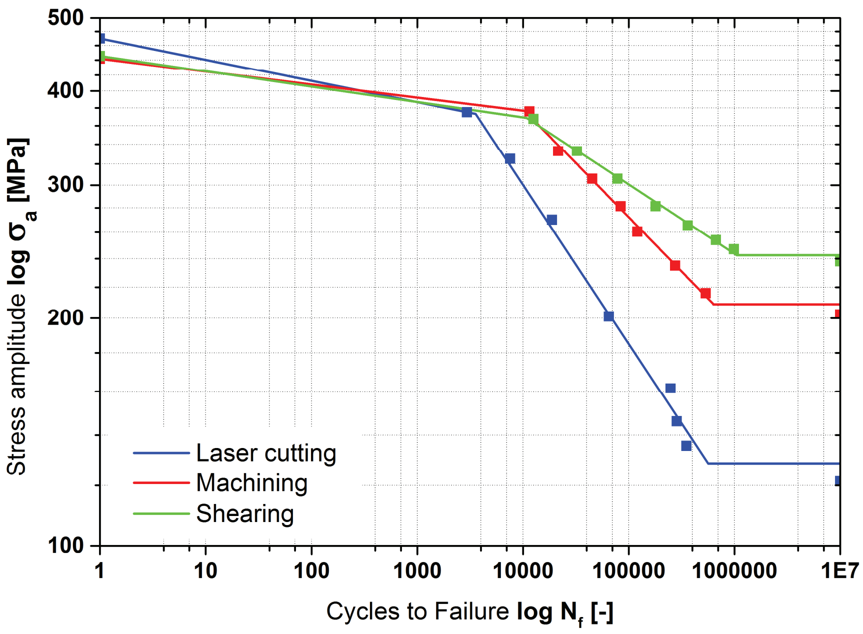


Fig. 8 Wöhler´s curves of TRIP steel RA-K 40/70 for different material cutting technologies

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