Failure analysis of the moving knife holder of a shredding machine

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Abstract: The paper focuses on the analysis of the causes that led to knife holder failure. The holder is a part of the car tyre shredding equipment. Based on the evaluation of the operating conditions of the machine, examination of the condition of the knife holder after the failure, analysis of the fractured surface as well as the material properties of the examined structural elements, it was possible to draw conclusions as to the reasons for the failure.

Keywords: shredding machine, tyre, knife holder, analysis of failure.

1 Introduction

One of the options for treating used tyres is to process them into a range of rubber granules. In the first stage of the recycling process, tyres are chopped into small pieces by the shredding machine (Fig. 1), which has stationary knives and a slowly rotating rotor with moving knives (Fig. 2). Fig. 3 shows the working area of the shredding machine during its operation – tyre shredding.

Fig. 1: General view of the shredding machine with a conveyor

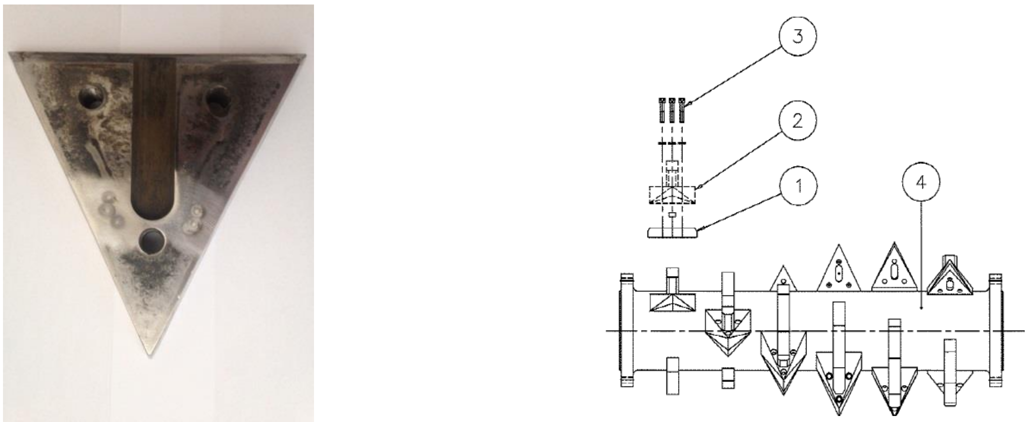
Fig. 2: Stationary and moving knives of the shredding machine

Fig. 3: Tyre shredding crushing in the shredding machine

The critical part of the shredder, where the breakage of the knife holder occurred, is the rotor in whose holders the moving knives are fixed with the bolts and the tongue. Their loading, wearing, subsequent grinding and adjusting are closely related to the fixed stationary knives. After approximately ten years of operation of the shredder, the moving knife holder broke. The paper presents the results of the examination of this failure and its analysis [1, 2, 3].

2 Description of the structural components of the tyre shredding machine

On the holders welded with fillet welds to the rotor of the shredding machine there are twelve cutting (moving) triangular knives (Fig.4a) arranged in two rows with six in each row (Fig.4b).

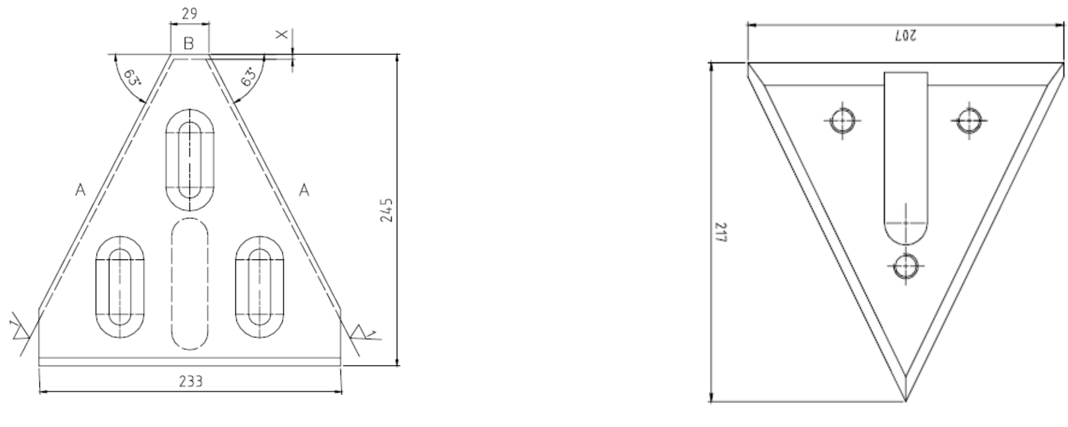


a) b)

Fig. 4: a) cutting (moving) knife, b) diagram of moving knives placement, 1 - moving knives, 2 – knife holder, 3 – bolts fixing the moving knives to the holder, 4 - rotor.

Stationary knives are fixed with bolts in the holders to the stationary parts of the machine. They are placed in one level with five full knives in the center and one half-knife at each end (Fig.2).

Tyres are shredded by the combined action of the moving and stationary knives during rotation of the machine rotor. Mechanical stress of the rotor substantially affects the sharpness of the knives‘edges as well as the size of the cutting gap between the knives. Therefore, optimal cutting conditions are provided by frequent adjusting and sharpening of the knives at the intervals specified in the instructions for the operation of the machine. The sizes and shapes of the of the stationary and moving knives are given in Fig. 5a where the cutting gap (0,2 + 0,5 mm) is adjusted by shifting the stationary knife in the grooves for bolted fixing.



a) b)

Fig. 5: Sizes and shapes of a) stationary knife, b) moving knife.

3 Failure analysis of the moving knife holder

Moving knives are fixed by three bolts in the holders (Fig.6) which are welded with fillet welds to the rotor of the shredding machine (Fig.2).

a) b)

Fig. 6: Knife holder with a moving knife- fixed by three bolts a) top view, b) side view.

The failed weld of the moving knife holder is shown in Fig.7a. The details of the failed weld joint of the holder are given in Fig. 7b; c. Fig.8 shows the fracture surface of the holder with the moving knife of the shredding machine, Fig.9 gives a view of the fracture surface on the rotor shaft of the shredder.

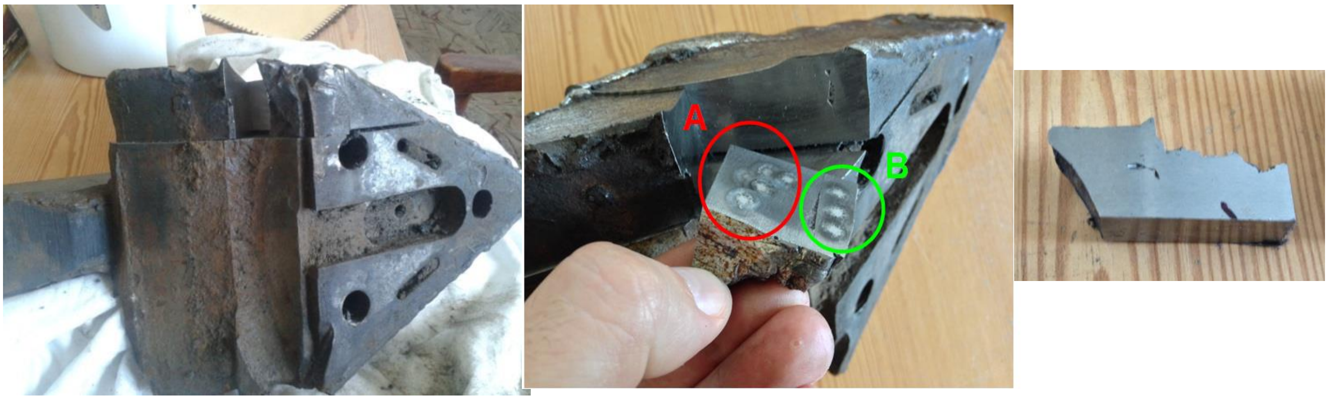
a) b) c)

Fig. 7: Failure of the welded joint of the moving knife holder a) general view , b), c) detailed view of the failed welded joint.

Fig. 8: Broken holder with moving knife

Fig. 9: Fractured surface on the shaft of the rotor

From Fig. 9 it is obvious that the fracture occurred in the location of the weld due to cyclic loading during the tyre shredding process. Samples were taken from the location of the fractured surface of the knife holder the in order to determine chemical composition and hardness as well as to perform metallographic analysis with the aim to identify material quality and assess its welding property (Fig.10a, b). In the samples, subsurface cracks were found in the locations of the welds (Fig.10c).



a) b) c)

Fig. 10: a, b) Locations where samples were taken and analysed, c) subsurface cracks in the samples a, b)

Chemical composition was determined by spectrometric analysis in two areas: A and B (Fig. 10b) since two different materials were used there. To adjust the moving knives, steel plates were welded to the holders to support the knives. Table 1 and Table 2 contain average values of the chemical composition obtained by measurement and chemical composition of these materials determined on the basis of the data as given in [4].

Tab. 1: Chemical composition for area A (knife holder) (wt %).

	C	Si	Mn	P	S	Cr	Mo	Ni
Determined by measurement	0,21	0,27	0,917	0,011	<0,002	0,637	0,236	0,459
Material 21NiCrMo2	0,17-0,23	0,40	0,65-0,95	Max. 0,035	Max. 0,035	0,35-0,70	0,15-0,25	0,40-0,70

Tab. 2: Chemical composition for area B (steel plate) (wt%).

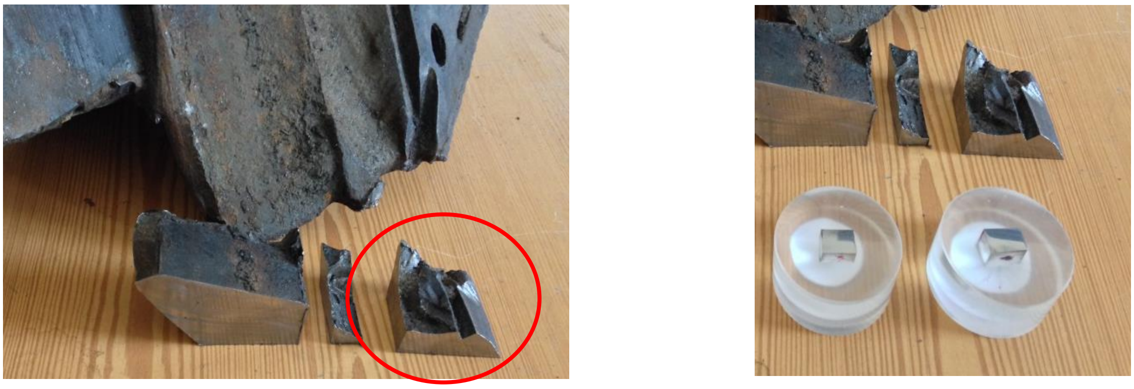
	C	Si	Mn	P	S	Cu	Cr	Ni	Ti
Determined by measurement	0,146	0,48	0,581	0,11	0,002	0,091	0,055	0,143	0,02
STN 411483	max. 0,20	max. 0,55	max. 1,40	max. 0,045	max. 0,045	max. 0,30	max. 0,30	max. 0,30	max. 0,20

The hardness of the moving knife holder material was measured using testing procedure according to Vickers (STN EN ISO 6507-1) or Rockwell (STN EN ISO 6508-1). Hardness values obtained by Vickers method were in the range 263 – 287 HV. Hardness measured on the Rockwell scale was 28 HRC. The value for the tensile strength of the material was then determined to be at m ≈ 950 MPa based on the above-mentioned values. Mechanical properties of 21NiCrMo2 material, which are given in Table 3, show that the tensile strength of the material of the moving knife holder was about 10% higher that the upper bound of the prescribed value.

Tab. 3: Prescribed mechanical properties of 21NiCrMo2 material

E [MPa]	R_m [MPa]	A_5 [%]	σ_c [MPa]	R_e [MPa]
200.000	650 – 880	8 - 25	275 - 275	350 - 550

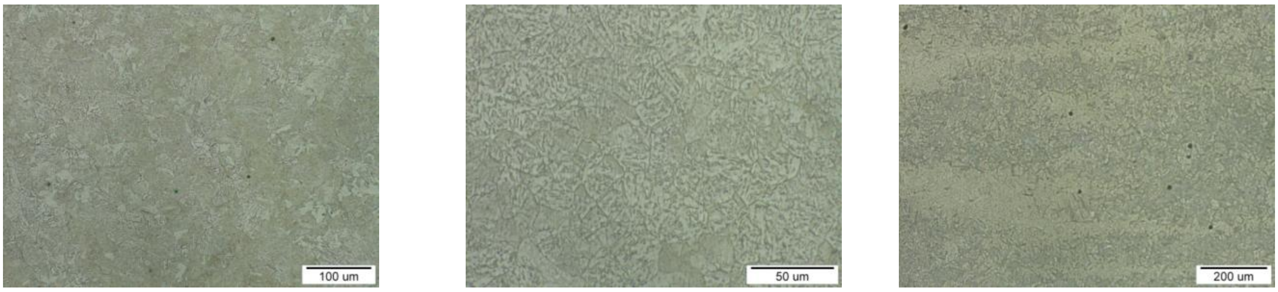
The place on the holder, from where the sample was taken for metallographic documentation, is shown in Fig. 11a. Metallographic analysis was performed in the cross-sections of two mutually perpendicular planes. Fig.11b shows the cuts in these planes.



a) b)

Fig. 11: a) Sample taken for the metallographic analysis, b) cuts in two mutually perpendicular planes

Microstructure of the material is shown in Fig.12 a,b,c.



a) b)

Fig. 12: a), b), c) microstructure of the material at various scales

Based on the results of the metallographic analysis of the basic material of the knife holder, it appeared that the structure of the material in both planes was identical.

Microstructure was built by ferritic-carbidic mixture with polyhedric grains and local linelike arrangement of the carbide particles.

Weldability of the material of the holder was assessed taking into account the chemical composition measured in accordance with the procedure in STN EN 1011-2 as given in Table 1. The analysis showed that the material was weldable with preheating to 150° - 180°C.

Material of the moving knife was also assessed. Table 4 gives average values of the chemical composition determined by measurement as well as chemical composition of the corresponding quality of the material - steel STN 419 56.

Tab. 4: Chemical composition of the material of the moving knife (wt%).

	C	Si	Mn	P	S	Cr	Mo	V
Determined by measurement	0,568	0,762	0,277	<0,0 02	0,003	5,43	1,42	0,92
STN 419569	0,58-0,68	0,70-1,1	0,25-0,55	max. 0,030	Max. 0,035	4,5-5,5	0,8-1,2	0,20-0,40

The measured value of the material hardness was determined to be 53 HRC.

According to the information provided by the operator of the shredding machine, the hardness of the knives declared by the supplier was 59 HRC. This hardness for 19 569 steel is obtained by its tempering at the temperature of about 200°C [4, 5], that is why the measured hardness of 53 HRC indicated that the knife material was tempered at the significantly higher temperature.

4 Conclusion

On the basis of the analysis of the operating conditions of the used tyres shredding machine, assessment of the condition of the moving knife holder after its failure, analysis of the fractured surface and material properties of the holder and the knife, the following conclusions can be drawn:

- Based on the chemical composition it was determined that the failed material conformed to the prescribed quality– steel 21 NiCr Mo 2,
- Material hardness was 28 HRC, which corresponded to the material strength of 950 MPa,
- Microstructure was built by ferritic-carbidic mixture with polyhedric grains and local linelike arrangement of the carbide particles.
- The analysed part of the machine failed due to the repetitive mechanical stress. Fatigue failure initiated at a point of a defective, poor quality weld and stress concentration ,
- The failure could also occur because of the increased mechanical stress of the welds of the holder of the moving knife as it was not supported by the holder along its whole length (Fig.6b).
- Another cause of the failure could be attributed to improper thermal processing of the material of the moving knife that led to wear and the increase of shear force during tyre shredding.

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