

ANALYSIS AND RESEARCH OF THE CAUSES
OF DAMAGE OF TECHNOLOGICAL DETAILS
OF ENGINEERING PRODUCTS

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Abstract

The state of damaged details of the investigated engineering products was analyzed: hopper of a truck car, car rim, structural assembly of an elevator. A chemical and spectral analysis of the material of the damaged part was carried out. The technical documentation of the engineering products was analyzed. Chemical and spectral analysis protocols have been studied and analyzed. Non-destructive testing of the investigates details was carried out. The probable causes of the accident of the investigated details have been established.

Key words: engineering details, chemical and spectral analysis, non-destructive testing, standards

Introduction. Steel is an alloy of iron and carbon in which the carbon content varies from 0.025% to 2.14%. In addition to carbon, steels also contain other elements – manganese, phosphorus, sulphur, silicon, traces of oxygen, nitrogen and aluminium, which are usually divided into alloying elements and impurities. Elements purposefully included in the composition of steel in order to modify certain of its properties are called alloying elements. The most commonly used alloying elements are manganese, nickel, chromium, molybdenum, boron, titanium, vanadium, and niobium.

Steel is the main production of ferrous metallurgy. In addition, approximately 90% of all steels produced in the world are carbon (ordinary) steels. The remaining

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10% are alloy steels. These are steels in which more special mechanical and other properties are obtained by adding other chemical elements such as chromium, nickel, tungsten, vanadium, molybdenum, cobalt, and others, or a combination of them.

Industrially produced carbon steel is a chemically complex alloy. In addition to the iron base, the content of which can be changed within the range of 97–99.5%, it contains many elements, the presence of which is determined by the technological features of production (manganese, silicon) or by the impossibility of their complete removal from the metal (sulphur, phosphorus, oxygen, nitrogen, hydrogen) and also from accidental circumstances (chromium, nickel, copper, and others). But one element, namely carbon, is specifically introduced into ordinary carbon steel. Carbon greatly affects the properties of steel even with a slight change in its content. Therefore, with a low content of all other possible impurities, the main element, with the help of which the properties of the iron alloy are changed, is carbon. It is therefore natural that these alloys (at $C \leq 2\%$) are called carbon steels. Iron-carbon alloys always contain more than two elements, and carbon (C), silicon (Si), manganese (Mn), phosphorus (P), and sulphur (S) are always present. The properties of steel are largely determined by the content of these elements, and in carbon steels this content must be minimal (especially phosphorus and sulphur). Carbon has the greatest influence on steel quality. The classification of steels is based on their carbon content, indicating the content of alloying elements. As carbon content increases, strength and hardness increase, while elongation and impact toughness decrease [1].

Aluminium alloy wheels have gained immense popularity, which is mainly due to their proven advantages. The aluminium alloys from which the rims are made are much lighter than steel. The most commonly used aluminium alloy for rims is A356 (AlSi7Mg0.3) in three modifications: A356.0; A356.1; A356.2. The chemical composition of the first modification is as follows: Si: $6.5 \pm 7.5\%$; Mg: $0.25 \pm 0.45\%$; Fe: 0.2%; Cu: 0.2%; Zn: 0.1%; Mn: 0.1%; Ti: 0.2%; Al – the rest. The lighter weight of aluminium alloys not only reduces over sprung weight, but also helps improve vehicle performance and handling. In addition, being lighter, alloy wheels provide better tire grip, help improve mileage and reduce stress on the vehicle. In comparison with steel wheels aluminium rims dissipate heat much better. When the tires get hot while driving, and especially when we apply the brakes, the heat will not last long, as aluminium wheels have the property of quickly dissipating the heat. This quality helps both to extend the life and protects the brake system and especially the brake pads from rapid wear. As alloy wheels are lighter, this effectively means that the car carries 'less' weight and will therefore reduce fuel consumption. Aluminium alloys are known to not corrode or rust. Therefore, the aluminium alloy rims also do not corrode or rust. As aluminium wheels dissipate heat, this has a positive effect on tire life. Car tires do not tolerate heat very well and tend to wear faster when heated. If equipped with aluminium alloy

wheels, the tires stay cool and thus extend their life. The main disadvantages of aluminium alloy wheels are as follows: they are not as strong as steel ones. This makes perfect sense given the fact that steel is one of the strongest materials, while aluminium is quite soft and malleable. This makes aluminium rims not very suitable for use on uneven terrain, as they bend and deform more easily than steel rims. Aluminium wheels have a higher price because the manufacturing processes of alloy wheels are more expensive and the price of the finished product is higher. Aluminium rims are not suitable for winter. Their reduced weight, which brings many benefits to the car's efficiency in other seasons, is a disadvantage in winter conditions. The lower weight of aluminium wheels does not allow winter tires to provide as good grip on snow and slippery roads as steel wheels. That is why most drivers use aluminium rims in summer and steel rims in winter [1]. The main goal of this work is to establish the probable cause of damage of technological details of engineering products.

Experimental part: analysis of technical documentation (certificate of conformity; protocols of spectral and chemical analysis; standardization documents); mechanical investigations and non-destructive testing. The tensile strength tests (R_m , MPa) are carried out according to BS EN 10002 – 1:2000 on standard samples with a diameter 102 mm and length 50 mm (A_5 – specific elongation, %; Z – reduction of area, %; HB – Rockwell hardness).

Inquiries were carried out in the Laboratory of nondestructive testing in IMSETHAC-BAS, License O-1193 registration number 04328 for using of ionizing ray sources for scientific and economic purposes. Non-destructive control with radiation methods and with Roentgen defectoscope of type 200/5 model MXR-200. Technical parameters: spot focus 2.45×2.80 mm; anode current 5 mA; tension 180 kV at measured equivalent dose 0.210 mSv with tapping $\pm 0.8\%$. Work conditions and reading of the roentgenograms are in conformity with Standards BDS EN ISO [2, 3].

Element of non-destructive testing: X-rays or gamma rays are used in radiation testing methods. They penetrate optically opaque bodies and act on photographic films in a similar way to light rays. Under their action, some substances, such as zinc sulphide, shine (luminescence).

Hopper of a truck car. In the technical documentation (certificate of conformity) [2] of ISUZU NQR 70 specialized trucks with a special container for hopper-top panel, side panels, base and hamper-side walls, base are indicated as 3, 2, 3, 3, 4 mm, respectively, St-52 (St with Latin letters). According to the International system of measurement units SI valid in the Republic of Bulgaria, mm are written with Latin letters (Table 1). In the first analysis (Act No. 44/9043/2004) for taking and developing an average sample) [3], it is noted that an “average sample of sheet metal St. 52-3 mm” (steel written in Cyrillic – St.), without indicating the place from which the sample was taken – from the base of the hopper or from the side walls of the hamper. According to the technical

documentation, the base of the hopper and the side walls of the hamper are made of 3 mm steel material – St-52 (St with Latin). The second sample was analyzed in the Institute of Metal Science, Equipment and Technologies with Hydro- and Aerodynamics Centre “Acad. A. Balevski”, (IMSETHAC) at the Bulgarian Academy of Sciences. In the test protocol No. B-771/2004 [4], a steel sheet 3 mm St. 52 (St. again with Cyrillic).

Car rim. The welding joints of the rim of a light truck were examined and analyzed by capillary non-destructive control penetrants. The resulting radiographs are presented in Fig. 1. As a result of control analysis with penetrating liquids, it was found that after repair (welding) of the rim of light truck, in the welding joints unacceptable by standards [5, 6] pores with a diameter of 2 ± 5 mm are observed. As a result, poor quality welding joints lead to an emergency situation with the rim and hence the light truck. The resulting radiographs are presented in Fig. 1.



Fig. 1. PT control of welding joints a), and b) $\times 5$

Cabin condition after the accident. After the accident, the following was found: The diameter of the deflection roller is 120 mm, and the diameter of the supporting rope is 10 mm. Both load-bearing ropes were broken under the influence of the weight. According to the manufacturer’s instructions, at 10 floors plus engine room, the ropes should have a diameter of not less than 11 mm, while the diameter of the supporting ropes installed after the reconstruction and at the moment is 10 mm, i.e. less than the requirements. There are many broken wires on the ropes and shavings from them on the lifter and on the cabin. No quality certificates are presented for the supporting ropes. The lift had been reconstructed, replacing the old lifting mechanism with 2 ropes (60/146 of type) with new of a different type for 4 ropes. The two ropes are placed next to each other, they should be placed across each other. The lifter has a small friction washer. The wedge mechanism (right wedge – cartridge with roller) did not work effectively (Fig. 2). There are signs of friction on the right rail of the “T” profile on the inside of the 3rd floor. No visible signs of friction were found on the

other rail. There are also no signs of friction on the roller cassette and the roller (wedge mechanism) which means that the same has not been activated. Figure 3 shows radiographs of weld joints from the box holding the ropes, obtained through non-destructive testing methods.



Fig. 2. Lifting mechanisms and “T” profile



Fig. 3. Radiographs of welding joints

Analysis of results. 1) In the technical documentation, there is a confusion of the brand of steel of the car. According to German standard DIN the brand of steel from which the hopper is made – St 52 is written with Latin letters. While according to the Bulgarian State Standard (BDS 5785-83): Quality carbon structural steels are written in Cyrillic and are denoted by numbers showing the average carbon content in hundredths of a percent – for example “St 08” means steel that contains $0.05 \pm 0.12\%$ C, “St 20” means steel that contains $0.17 \pm 0.24\%$ C, “St 45” – steel with $0.42 \pm 0.50\%$ C, etc. [7]. Or in the specific case: “St 10” is steel that contains, for example, $0.08 \pm 0.12\%$ C; “St 52” is steel that contains approximately $0.46 \pm 0.58\%$ C. There is one mixing of German standard with BDS and vice versa: mechanically transfer the principle of classifying steel grades according to BDS to the German standard and vice versa. I.e. the mark St 52 does not mean that the steel contains on average 0.52% C, but contains $\leq 0.20\%$ C in accordance with the German standard DIN 1629 (Table 1).

If we allow that steel grade St 52 given in the technical documentation of the ISUZU truck complies with the German DIN standard, it has a chemical

composition given in Table 1. According to protocol No. B-771/2004, the steel brand corresponds to the technical documentation of the car, while according to Act No. 44/9043/2004, the steel brand can be determined according to the German standard as C 45. In such cases, a new test by chemical analysis of a control (third) sample; witness sample; or taking a new sample is recommended.

T a b l e 1
Chemical composition of the steels

Brand steel	Chemical composition, weight %					Standard
	C, %	Si, %	Mn, %	P, %	S, %	
St 52	≤ 0.20	≤ 0.55	≤ 1.50	≤ 0.050	≤ 0.050	No. 1.0580 DIN 1629 B1.001627
IMSETHAC	0.07	0.19	0.55	0.014	0.013	
with 45	0.42–0.50	0.15–0.35	0.50–0.80	0.045	0.045	No. 1.0503 DIN 17200; 17242; 1652
Bulgar – control	0.47	0.18	0.53	–	0.022	

ISUZU NQR 70 truck was investigated using non-destructive testing methods. Defects were found in the welding joints of the base and hamper-side [8–10].

2) The old lifting mechanism of the elevator is type 60/146. According to the manufacturer's instructions, the ropes should have a diameter of not less than 11 mm, since the number of floors is 10 stops plus machine room. It has been established that the diameter of the supporting ropes after the reconstruction is still smaller, i.e. it does not meet the requirements – 10 mm. It was found that the reason for the rapid wear and tear of the supporting ropes was the small size of the deflection roller. It has an outer diameter of 12 mm. As required the ratio between the divider diameter of the friction washers, drums and rollers of the ropes and the nominal diameter of the supporting ropes must be at least 40, regardless of the number of wire bundles.

Conclusions. 1) It was established that in the technical documentation of the ISUZU NQR 70 truck, the St 52 steel brand is according to the German DIN standard. Therefore, the carbon content of the brand is less than or equal to 0.20%. Two test results have been received. The values of carbon differ by 0.40%, with relatively close values of the other alloying elements. For a relatively accurate analysis such as chemical analysis, such a difference is considered large. In practice, as a result of the chemical analysis, two different grades of steel have been determined:

- according to the first analysis, the steel corresponds to the brand specified in the certificate of conformity, i.e. this is St 52;
- according to the second analysis, the steel does not meet the requirements

specified in the certificate of conformity, i.e. it is C 45 steel (Table 1).

If the data on the technical characteristics of the two steel brands St 52 and C 45 are analyzed, the following conclusion can be drawn: there is a difference in the technical characteristics of the two steel brands in terms of yield strength – R_o , tensile strength – R_m , relative deformation (elongation) – A_5 . The difference is most significant in tensile strength. Of the two steel brands St 52 and C 45, determined as a result of the chemical analysis, with higher values of the mechanical characteristics: yield strength – R_o , tensile strength – R_m , relative deformation (elongation) – A_5 is steel C 45. This steel has values of mechanical characteristics as follows: R_o from 480 ± 375 MPa, R_m from 700 ± 800 to 620 ± 760 MPa, A_5 from $14 \pm 17\%$ depending on the size of the forging (roll). While for steel St 52 -3 the values are $R_o \geq 355$ MPa, $R_m \geq 510 \div 610$ MPa, $A_5 \geq 22(16)\%$, respectively.

Of the two grades of steel St 52 and C 45, determined in two independent accredited laboratories, a greater overload (tensile), which is also the main one for this type of truck, would withstand steel C 45.

Regardless of the results obtained from the two analyses, in one case the material complies with the technical documentation (certificate of conformity) and is St 52 (according to protocol No. B-771/2004). In the other case, according to the chemical analysis (Act No. 44/9043/2004), steel C 45 has higher values of mechanical characteristics and would withstand greater tensile overload. Therefore, in both cases as a material the base of the hopper (respectively the side walls of the hamper) as a brand of steel corresponds to the technical documentation (certificate of conformity) or surpasses it (for steel C 45). From everything stated up to here the main conclusion is that the brand of steel is not among the probable reasons for the failure of the (hopper) of an ISUZU NQR 70 car. As the most probable causes of the failure of the (hopper) of the truck outlines the quality of the weld joints. Other reasons are also possible, such as overloading the car beyond the permissible limit.

2) Welded joints of a light truck rim were investigated and analyzed by capillary non-destructive testing penetrants. As a result of a control analysis with penetrant liquids it was found that after repair (welding) of the rim of a light truck, in the welding joints, inadmissible pores with a diameter of 2 ± 5 mm were observed. As a result, poor-quality welding joints lead to an emergency situation with the rim and therefore on the light truck.

3) It has been established that the reason for the rapid wear and tear of the supporting ropes is the small size of the deflection pulley with an outer diameter of 120 mm. As required, the ratio between the pitch diameter of the friction washers, drums and rollers of the ropes and the nominal diameter of the supporting ropes should be at least 40, regardless of the number of wire bundles. The supporting ropes are worn out with numerous broken wires and shavings from them on the lifting mechanism and on the cabin.

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