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Mechanical Tests Performed on Rubber Plates Used on Railway Vehicles

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Abstract. *In order to place a product on the market that is completely safe for users, the manufacturer must go through certain steps: design, prototyping, execution and prototype validation through experimental methods, obtaining documents that allow to sell the product from certain public or private companies (for example homologation certificate) and series production. One of the most important steps is the validation tests of the prototype because it will depend on them that the prototype corresponds to the design requirements.*

Keywords*: mechanical tests, rubber, railway vehicles*

1. Introduction

In the field of mechanical engineering, the most used material has been steel for many years. For example, in the railway transport industry, the vehicles were built only with steel for years. The design of strength structures (car body or bogie frame) built of steel was done using analytical methods [1].

These methods used in the railways were purely strength of the materials methods. However complicated a structure may be, it can be reduced to simple models [2].

Gradually, for economic reasons, to reduce the weight of vehicles, aluminium began to be used to replace steel. Any railway operator wants to transport as much as possible, which is possible by reducing the mass of freight wagons [3].

Then, components made of plastics or composite materials were used by railways. Studies have shown that these materials can be successfully used in the construction of rolling stock and in the automotive field [4, 5].

On the other hand, analytical methods have gradually been replaced by numerical methods [6]. In this way, railway constructions have become increasingly complex due to computer-aided design.

In the railway industry, rubber, plastics and composites materials are used in the construction of rolling stock as well as in the construction of the track infrastructure. Thus, panels made of composite materials are used for passenger cars to make the walls. Plastic is used to build the elements of interior furniture but also as an intermediate element between rails and sleepers. Although rubber did not play a major role in the construction of strength structure of railway vehicles, it was widely used in components of tramway or subway wheels, suspension elements, for vibration isolation, electrical cable insulation etc. In the case of railway vehicles, where elastic elements are needed, rubber is used for the construction of buffers, traction couples, vehicle suspension [7].

Rubber is a technical product consisting of a macromolecular compound with linear, long, flexible chains and having elastomer behavior. Numerous types of rubber are produced and used (natural rubber, synthetic rubber), each of them having certain advantages and disadvantages in specific uses. The rubber macromolecules can move relative to each other under the action of mechanical stress.

Natural rubber is a product of vegetable origin that contains 93-94% polyisoprene rubber hydrocarbon and other components: oleic acid, linoleic acid, stearic acid, sterols, carbohydrates, carotenoids.

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Natural rubber is water stable, does not dissolve in alcohol, acetone, is slightly soluble in esters, higher ketones, but dissolves in toluene, xylene, gasoline, carbon tetrachloride, chloroform, carbon sulfide. Due to high unsaturation, natural rubber reacts with oxygen, ozone, halogens, halogenated acids, maleic anhydride (butandioic acid), thioacids, mercaptans. Natural rubber reacts easily with oxygen with the destruction of macromolecules. UV radiation causes destruction followed by structuring.

Natural rubber is used as the only rubber in compositions or in combination with other rubbers with which it is miscible on a macroscopic scale: synthetic isoprene, butadiene, butadiene-styrene. The vast majority of compositions use carbon black.

Synthetic rubbers are synthetic polymers that can be processed and vulcanized similar to natural rubber. Most synthetic rubbers are mixed with batches, vulcanizing agents and other ingredients and then subjected to vulcanization. The high elasticity of rubbers and vulcanizers is due to the properties of the macromolecules from which they are formed, mainly to the flexibility of their chains. Synthetic rubbers and their vulcanizers are typical elastomers. The vulcanization capacity is given by the presence in macromolecules of some reactive centers with whose participation intermolecular bonds are formed. The presence of these reactive centers also determines the possibility of degradation under the action of atmospheric factors or the working environment as well as the possibility of transformation by chemical reactions which, as a rule, greatly modify the physical properties of the rubbers.

The rubber mixture used for tests is NBR - butadiene acrylonitrile (34% ACN) with a density of 1,23 g/cm^3. The composition is given in the following Table:

No.	Ingredients	Chemical formula	Parts by mass	Percents by mass
1	NBR Butadiene acrylonitrile	-(CH_2-CH=CH-CH_2)- -(CH_2=CH-CN)	100	56.43%
2	HAF N550 carbon black	C	65	36.68%
3	Zinc oxyde	ZnO	5	2.82%
4	Stearic acid	$CH_3(CH_2)_{16}CO_2H$	1	0.57%
5	Antidegradant TMQ (polymer)	2,2,4 - trimethyl - 1,2 - dihydroquinoline $C_{12}H_{16}NO_2$	2	1.13%
6	Accelerator TMTD	tetramethyl thyuram disulphyde $C_6H_{12}N_2S_4$	2.5	1.41%
7	Accelerator CBS	n - cyclohexyl benzothyazole - 2 - sulphenamide $C_{13}H_{16}N_2S_2$	1.5	0.85%
8	Sulphur	S	0.2	0.11%
9	Total		177.2	100%

The conditions of vulcanization were as follows: a period of 20 min at a temperature of 160^{0}C.

2. Materials and methods

We can split the railway system into several subsystems: infrastructure (rails, platforms, stations), rolling stock (locomotives, wagons), energy (all equipment that supplies electricity to the railway system), control - command - signalling (traffic control facilities).

Before putting in service one of the above subsystems (or components thereof), they must be approved, which certifies that each product introduced into the system complies with a minimum set of rules. But in order to homologate/certify a product, it must first start with the design stage. At this stage, starting from the basic concepts of strength of the materials, the future product is designed for static and dynamic loads [8, 9]. Then the project becomes a prototype and it is validated in different testing stages.

This paper presents the tests and the results performed on rubber components used in the railways.

In the validation process of a product, the tests may be performed on products or on specimens made of material identical to that from which the products was made. In some cases, the samples are extracted from the product itself. Test methods for rubber components are described in the literature or in

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standards. Regarding the technical literature, important information can be found in [10, 11].

The tests used for the approval of products are carried out in accordance with international and/or national standards [12, 13]. Where acceptance criteria (limit values) are not imposed in the standards, the manufacturer shall establish the acceptance criteria in agreement with the end user.

The following equipment was used to perform hardness, tensile and compression tests on five-piece rubber plates/samples (F1…F5) measuring 150 mm x 150 mm x 2 mm:

- Calliper;
- Shore A hardness tester;
- Universal testing machine;
- Climate chamber;
- Thermometers.

2.1. Determination of Shore A Hardness

Hardness is technically defined as the resistance of the material to the mechanical penetration of a harder body from the outside.

Shore hardness can be divided into the following scales:

- scale A for normal hardness of rubber;
- scale D for high hardness of rubber;
- scale AO for low hardness of rubber;
- scale AM for thin rubber specimens in the range of normal hardness;

The Shore hardness is used to determine the indentation hardness of materials ranging from cellular products to rigid plastics. The Shore A hardness tester (Figure 1) is a portable measuring instrument, much smaller than the metal hardness tester. Prior to the tests, it is checked with a set of rubber blocks (Figure 1), even if the hardness tester is metrological checked.

Figure 1. Shore A hardness tester and rubber test/calibration blocks

The values of Shore A hardness calibration blocks are presented in Table 1.

Table 1. Shore A test blocks hardness values

Violet	Brown	Green	Orange	Red	Yellow	Grey
24	35	50	55	71	78	87

2.2. Determination of breaking strength and relative elongation at break

For this test, a universal testing machine was used. The machine can statically test for tensile, compression and bending rubber specimens. The universal machine is the 10 kN Testometric M350 brand (Figure 2).

Figure 2. Universal testing machine Testometric M350-10kN

Five type 1 dumbbell-shaped specimens extracted from the rubber plates were used in the tests. After being mounted on the holding grips of the universal testing machine, the specimens were subjected to tensile with a speed of 500 mm/min, according to [7]. The test machine graphically plots the force-deformation curve and numerically saves the values corresponding to the points on the graph. In addition, it is calculated:

$$E_b = 100\,\frac{L_b - L_0}{L_0}\ [\%] \quad (1)$$

where: E_b is the relative tensile elongation at break, L_b is the breaking test length in mm and L_0 the initial test length in mm (usually 50 mm gauge length using an contact extensometer).

Starting from the measurement results, other parameters can be calculated such as: tensile strength at break, relative tensile elongation at break etc.

2.3. Determination of residual deformation at 25% compression

Four Ø 29x12.5 mm cylindrical specimens were used to perform this test, the initial thickness of which was measured, then they were subjected to 25% compression for 24 h at a temperature of 100°C, after which they were relaxed for 30 min and the thickness was measured again. The remaining deformation was calculated with the expression:

$$C = 100\,\frac{h_0 - h_s}{h_0 - h_1} \quad (2)$$

where: h_o is the initial thickness, h_1 represents the thickness after compression of 25% and h_s is the final thickness after 24 h compression and then relaxation for 30 min, according to [6].

The Figure 3 shows the device by means of which the specimens were subjected to compression during maintenance in the climatic chamber.

Figure 3. Specimen compression device

3. Results and discussions

3.1. Determination of Shore A hardness

For each rubber plate/sample (F1...F5), the hardness was measured at 5 points, as follows: at the intersection of the diagonals and 10 mm away from each edge. The following values represents the arithmetic mean of the measurements for each rubber plate/sample, the tests being performed according to [11].

The summary of the results is presented in Table 2.

Table 2. Results for Shore A hardness test

Sample	Parameter		
	Hardness [ºSh A]	Average hardness, [ºSh A]	Limit of hardness [ºSh A]
F1	88.9	88.5	90±3
F2	88.3		
F3	88.7		
F4	88.5		
F5	88.1		

In the previous table, the limit value was imposed by the manufacturer and it has been transcribed in the “Limit” column.

The graphical representation of the results presented in Table 2 can be seen in Figures 4 and 5.

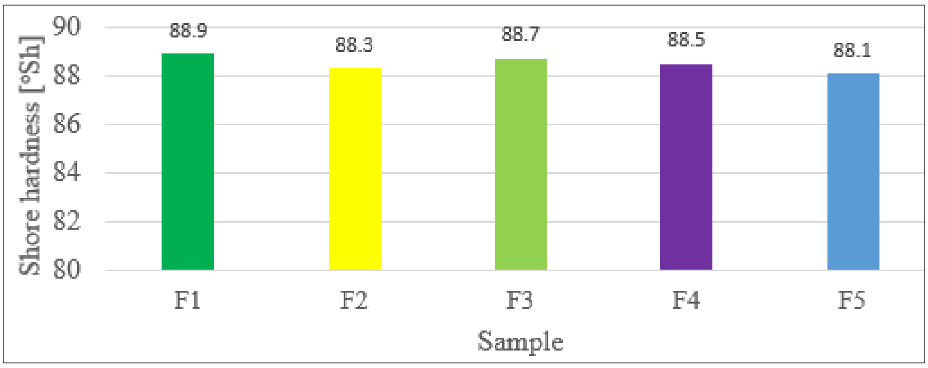

Figure 4. Average value of Shore A hardness for F1-F5 specimens/rubber plates

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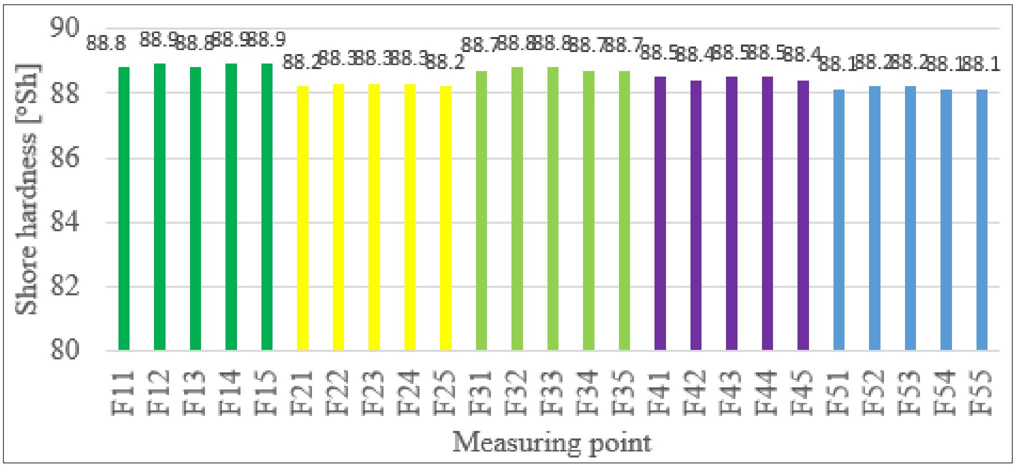

Figure 5. Measured values of Shore A hardness for F1-F5 specimens/rubber plates

3.2. Determination of breaking strength and relative elongation at break

Force versus elongation curves are presented in the next five figures.

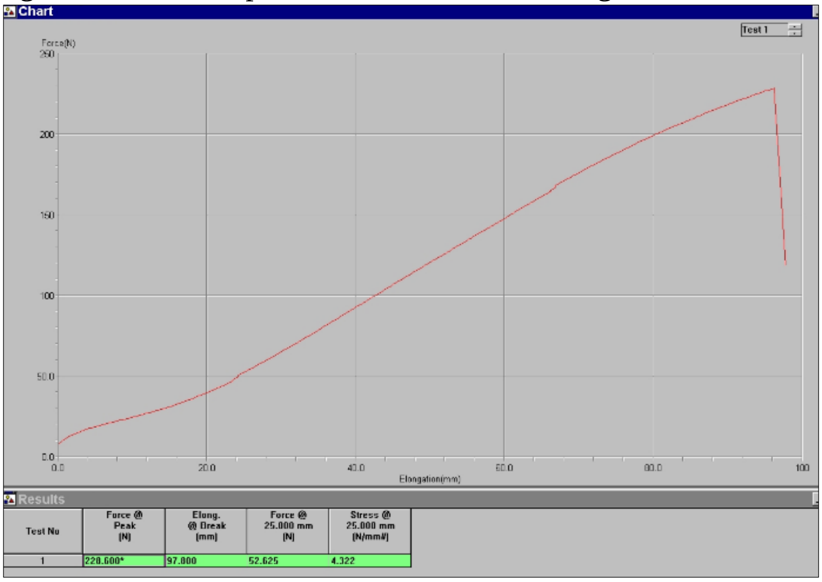

Figure 6. Force versus elongation curve for T1 specimen

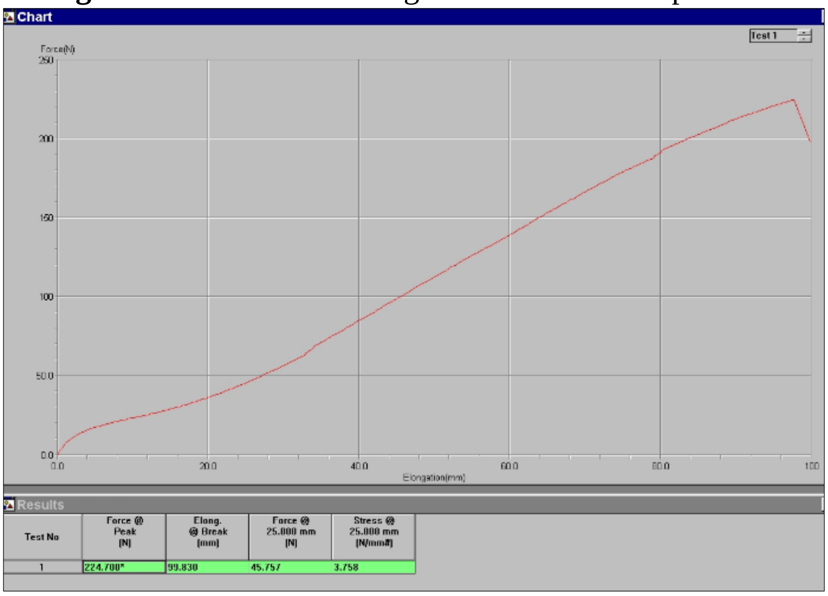

Figure 7. Force versus elongation curve for T2 specimen

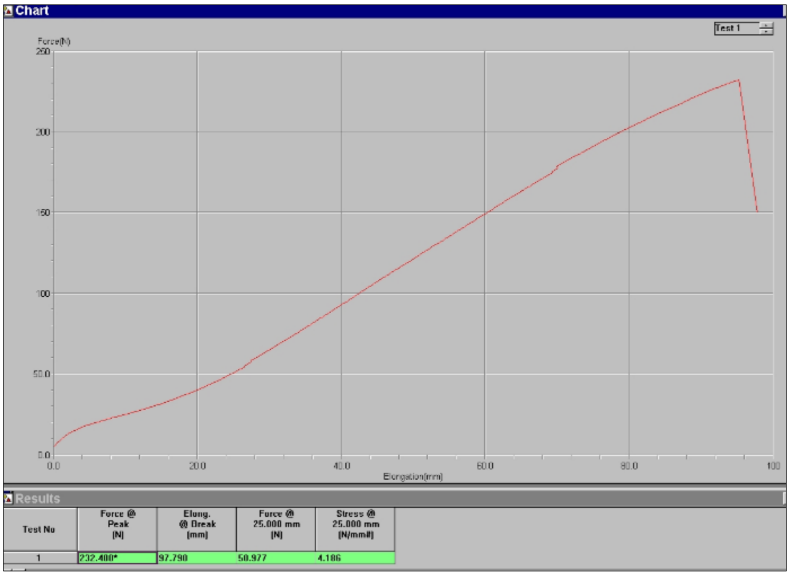

Figure 8. Force versus elongation curve for T3 specimen

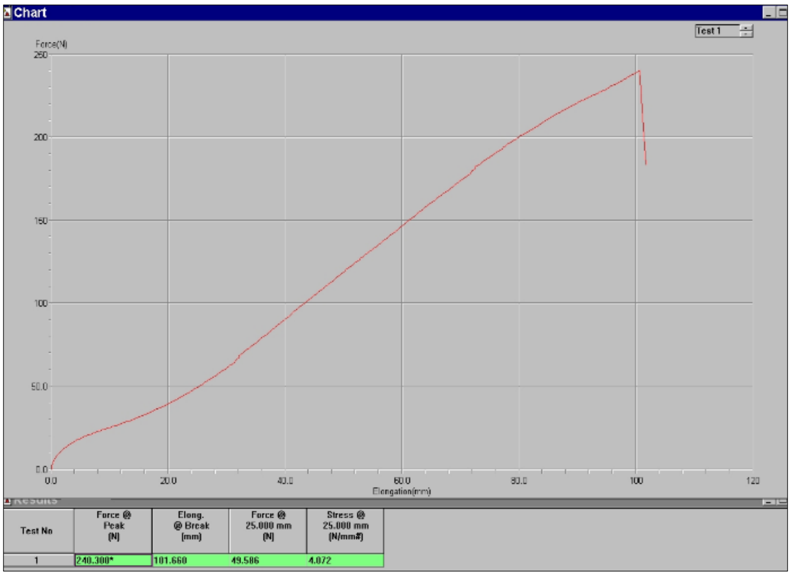

Figure 9. Force versus elongation curve for T4 specimen

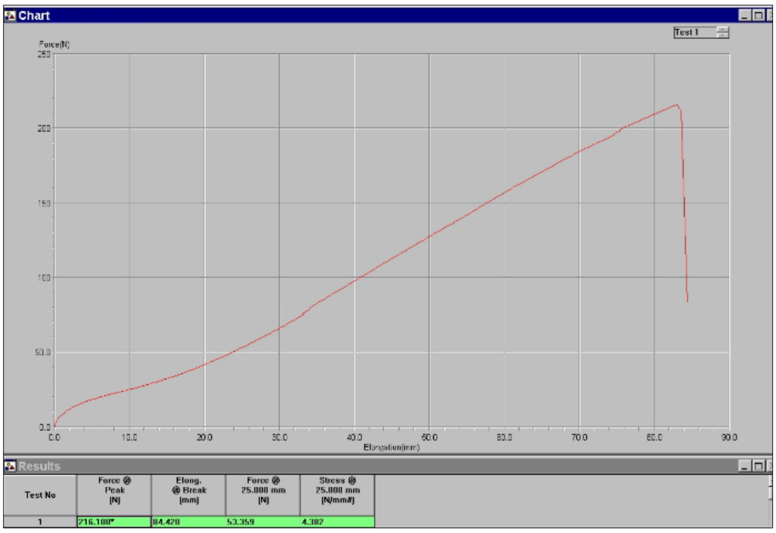

Figure 10. Force versus elongation curve for T5 specimen

The results can be seen in Table 3.

Table 3. Results of breaking strength and relative elongation determination

Sample	Area of shear section [mm^2]	Force at break [N]	Strength at break [N/mm^2]	Average strength at break [N/mm^2]	Limit of strength at break [N/mm^2]	Absolute elongation for tensile breaking [mm]	Relative elongation for tensile breaking [%]	Average relative elongation [%]	Limit of relative elongation [%]
T1	12.18	220.6	18.11	18.62	at least 15	97.0	194.0	192.3	at least 150
T2		224.7	18.45			99.83	199.7		
T3		232.4	19.08			97.79	195.6		
T4		240.3	19.73			101.66	203.3		
T5		216.1	17.74			84.42	168.8		

In the previous table, the limit value was imposed by the manufacturer and it has been transcribed in the “Limit” column.

3.3. Determination of residual deformation at 25% compression

The results can be seen in Table 4.

Table 4. Determination of residual deformation after 25% compression

Sample	h_0 [mm]	h_s [mm]	h_1 [mm]	Residual deformation [%]	Limit of residual deformation [%]
C1	12.28	11.81	9.27	15.61	at most 30
C2	12.34	11.90	9.27	14.33	
C3	12.43	11.96	9.27	14.87	
C4	12.38	11.87	9.27	16.39	

In the previous table, the limit value was imposed by the manufacturer and it has been transcribed in the “Limit” column.

3.4. Checking the test equipment before performing the tests

It is recommended that the laboratory equipment used in the measurements to be checked prior to the start of the test, even if it is metrological verified.

The Shore hardness tester is checked with the calibration blocks. In the case of the test machine, it measures the force by means of a force cell and the displacement by means of a displacement transducer. Checking the force cells is done by mounting another reference force cell in the holding grips of the universal testing machine. Care will be taken that the indication of the tested machine to be identical with the reference force cell. In the case of the displacement transducer, it is checked with a reference displacement transducer.

The following shows how to check the Shore hardness tester. For example, the grey calibration block has a Shore hardness value of 86.7^{o}ShA.

The values of the measurements made on the standard plate (test block) are shown in Table 5.

Table 5. Values obtained when checking the Shore hardness tester using the grey test block

Number of measurement	Measured value (^{0}ShA)	Average value $\overline{x}$ (^{0}ShA)	Standard deviation u_m (^{0}ShA)
1	87.5	87.38	0.21
2	87.2		
3	87.7		
4	87.4		
5	87.2		
6	87.6		
7	87.5		
8	87.4		
9	87.3		
10	87.0		

Measurement uncertainty in the calibration certificate of the test block is: $U_e = 1^0$ShA. It will result:

$$u_e = \frac{U_e}{2} = 0{,}5^o\text{ShA} \quad (3)$$

Measurement uncertainty in the Shore hardness tester calibration certificate: $U_d = 0{,}8^o$ShA.

$$u_d = \frac{U_d}{2} = 0{,}4^o\text{ShA} \quad (4)$$

The combined uncertainty is:

$$u_c = \sqrt{u_{calibration\ block}^2 + u_{hardness\ tester}^2 + u_{measured\ sample}^2} = 0{,}6739^o ShA \quad (5)$$

The extended uncertainty will be:

$$U_c = u_c \cdot 2 = 1{,}35^o\ ShA \quad (6)$$

The acceptability criterion for the use of the Shore A hardness tester is that the measured value ***x*** on the calibration block (before performing a series of measurements on the test object) should be within the range Standard value ± U_C.

4. Conclusions

The interest for rubber as a material, justified by its properties, triggered a series of research and experiments that led to the establishment of recipes (mixtures) and technologies for the execution of rubber parts, of different shapes and sizes, with characteristics specific to a wide range of uses, including rolling stock.

The basic characteristic of rubber is its great elasticity, respectively the ability to withstand large deformations under the action of external forces and to return to its original shape when the action of these forces ceases.

Tests performed on railway vehicle parts contribute to their safety, as the introduction of these products into the railway system is done after product certification following the validation of the project through testing. After testing in laboratories, the products shall be monitored in service to determine the behavior in service for a long period of time.

The material that was used to make the test specimens is in accordance with the reference standards used in the railway field.

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