Preservation of macro fractographic signs of the plane of fracture of the details for expert engineering research

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Abstract. Estimates of operational reliability and durability of machine parts and mechanisms cannot be carried out without technical diagnostics of the presence or absence of fatigue cracks, which are the cause of destruction. In some cases, the object of investigation, which is a material proof in the execution of expert engineering studies, may be accidentally or deliberately damaged or destroyed. This leads to the loss of specific signs of the presence of fatigue cracks and the inability to identify patterns that led to their appearance. Ultimately, this affects the reliability of the results. For example, such circumstances in the future significantly complicate the identification of the true causes of accidents and disasters on the railway. Preserving the plane of fracture of the object of research at the scene of the incident and in the process of its transportation to a research institution is an important factor in increasing the reliability of expert engineering and technical opinion taking into account the requirements of the European Union technical specifications (TSI).

1. Introduction

The stability of the development of the national economy depends on the degree of development of each of its branches and infrastructural components. European integration is one of the main priorities of Ukrainian state policy. The development of the railway industry of Ukraine is a prerequisite for stable development and recovery of the economy, strengthening its competitiveness, expanding its foreign economic activity in providing European integration vector for the development of the state. In this context, railway traffic safety remains one of the most important factors in the development of the industry, since without an adequate level of safety, the efficient operation of the entire railway segment is impossible.

Usually, the level of safety operation of the railway transport system depends, to a large extent, on the successful development of socio-economic programs of the state. But at the same time, along with the development of the railway system, the number and level of accidents and disasters, the death toll and the number of wounded people, and material losses to citizens and the state as a whole are increasing. In the investigation of rail-transport accidents (RTA) one of the main sources of evidence is the conclusion of the court rail-transport expertise.

Investigation of railway accidents is impossible without solving the problems of identification causal relationship between breakage (surface or internal) or destruction of a structural element and the time when the threat to safety movement on the railway transport occurs. Such tasks fall within the competence of experts with specialty “Research of vehicle parts”.

A number of recent studies have been devoted to the investigation of the causes of rolling stock derailments [1-3]. The development of track deformations and defects in its elements are outlined among the possible reasons the derailments. The initiation and the development of the track deformations are primarily associated with the residual settlements of ballast layer. A mathematical modelling of track unevenness development and calculations of rolling stock loading on ordinary track and turnouts is carried out in the studies [4-5]. The influence of the maintenance works and their influence on the quick initial deformations are studied in [6].

The study of the behaviour of the rolling stock and the railroad after the moment of derailment is presented in the papers [7-9]. One of the objectives of these studies is to establish the causes and the mechanism of railway traffic accidents by the help of tracking the superstructure destruction and the damages in track and rolling stock.

A series of papers [10-12] is devoted to preventing and forecasting the destruction of especially loaded track elements – the crossings of turnouts. These studies deal with an experimental observation of the rolling stock dynamic loading and appearing of cracks in the common crossing rails during its lifecycle. Both on-board and track monitoring systems of dynamic loads are used for this purpose.

A fractography study of metal surfaces in the destruction areas of rolling stock and railway track is presented to a number of studies [13-16]. The results of the studies allow to determine the conditions of the elements operation and the causes for the destruction as well as the defect prevention. An analysis of the cracks development in the rail rolling surface and the prediction of its development depending on the size and shape of cracks, is studied in [17-20].

The task of the forensic railway expert examination, in this case, is to identify technical conditions of systems and elements of railway transport in case of their loss of strength, studying the actions of participants of the railway transport accident (RTA).

2. Formulation of the problem

The practice of carrying out engineering and transport research at L’viv Research Institute of Forensic Expertise of the Ministry of Justice of Ukraine indicates that in certain cases, upon removal, the destroyed objects of investigation may have unintentionally or deliberately damaged planes of breakage, which leads to the loss of their specific features and inability to detect regularity, which led to the occurrence of damage and destruction, and hence the reliable identification of the causes of an accident or disaster is impossible. As a result, these circumstances, in the future, substantially complicate the establishment of actual causes of traffic accident occurrence, and in some cases, may lead to erroneous conclusions.

3. The purpose of the work

Provide recommendations for material evidence preservation as objects of engineering and technical research for the performance of court rail-transport expertise.

4. Main research material

From the theory of materials resistance it is known that the destruction of rolling stock parts is most likely due to the following reasons:

- if the quality of the metal which they are made of does not ensure mechanical properties provided by the design, such as the strength limit, hardness, impact strength, etc.;
- if their geometrical parameters do not meet the requirements of the working drawings (mismatch and distortion of linear dimensions, radii of quirks of parts, the presence of dints and scratches on the surface of the loaded parts, etc.);

- if the forces acting on the corresponding element of the moving mechanism of the vehicle exceed the maximum load that it can withstand.

However, it is also known from the expert practice in the research of machine parts and mechanisms of the railway industry that destruction occurs when the qualitative parameters of the metal which the part is made of, its geometric parameters correspond to the requirements of the normative documents, and the forces acting on the part do not exceeded the maximum load that this part can withstand. In such cases, it is necessary to apply the mechanics of destruction of solids with cracks. [21-25].

The criteria and approaches for assessing the strength of materials and structures formed at the beginning of the last century come from the fact that the calculation model of a real solid is a continuous medium with given rheological properties (for example, elastic continuum), and the deformable body element is located in one of these states: solid (*S*-state) or destroyed (*D*-state) (figure 1). The transition of a material element from the state *S* to the state *D* (the process of destruction) is carried out instantaneously as soon as the stress-strain state, calculated within the framework of the adopted rheological model, reaches some critical value (for example, if the tensile stress at the given point of the deformed solid reaches strength limits σ_B).

Such a classical approach to materials in a fragile state, which have sharpened defects such as cracks, cannot solve the task of their strength, because this approach does not take into account special stress-deformed state of the material in the vicinity of the peak of the acute defect that is a crack in the process of body deformation. This is due to the fact that the radius of peak rounding of such a concentrator is comparable to the parameters of the structure of the material itself.

The most important postulate in the mechanics of solid destruction is the interpretation of destruction as the process of origin and spread of a crack, which (in comparison with classical approaches) already involves the mechanism of destruction itself, and the crack becomes the instrument with which the destruction is carried out. This implies the importance of evaluating the extremely equilibrium state of solids with deformable cracks, as well as the development of a crack under the short-term or long-term impact on the body of the given workload and environment and determining the characteristics of the material resistance to spreading cracks in it, that is the crack-resistance of the material.

The main idea of the neoclassical approach (mechanics of material destruction) is reduced to the following (figure 1). It is believed that the transition of an element of a deformed body from the state *S* to state *D* is accompanied by an intermediate state *I*, which must be taken into account when solving the problem of body strength with defects such as cracks. The most important feature of a deformable solid, where the state *I* (area before deformation) arises is that its material is always deformed beyond the limits of elasticity, and precisely there the most intense plastic deformation, diffusion processes, material damage and other phenomena, which ultimately lead to local destruction of the material, that is, $S \rightarrow I \rightarrow D$ transition takes place. Thus, the neoclassical destruction scheme involves allowance of *I*-state of near-sharp defects in a deformed body and, first of all, stress concentrators of crack type whose radii of curvatures are comparable to the typical linear size of the structural element of the material.

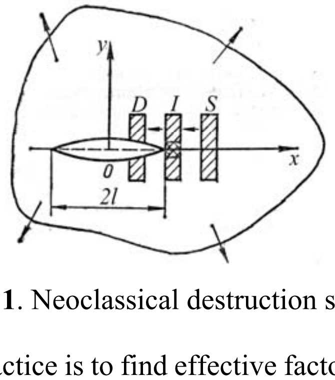

Figure 1. Neoclassical destruction scheme.

The direct task for engineering practice is to find effective factors for increasing the index of friction resistance. However, in expert practice, there is a need to study the inverse problem – what coursed the problem and how actually the process of destruction took place.

In analysing the causes of fatigue destruction of machine parts, mechanisms and elements of steel structures, the forensic expert practice investigates the structure of fracture planes. Also, for the analysis of reasons of cracks origin, metallographic methods of research are used to determine the size, shape and mutual placement of crystals, structural features, as well as non-metallic inclusions, cracks, shells, pores, etc. They distinguish macroscopic and microscopic methods of investigating the structure of surfaces of fracture planes.

The macroscopic method is a study of the structure of metals with the naked eye or with the use of a magnifier or microscope with magnification of 5-30 times; it makes it possible to detect holes on the fracture planes of shells, slag inclusions, damage of the structure continuity (macro- and microcracks), and other defects of the metal structure, which product is made of. They show chemical, structural heterogeneity of a metal and deviations from the regulatory requirements.

If macrofractographic studies do not show visible defects in a metal product, then the microscopic analysis of the structure is used, which consists in using optical or electronic microscopes on specially prepared samples, to determine the cause of the destruction. These samples are cut from fragments of destroyed parts, which have already entailed the destruction of the object of research, which, as a rule, is a real evidence of the case. Therefore, ensuring the safety of detected planes of fracture parts of rolling stock at the place of railway accident and in the process of their transporting to an expert institution is an important factor in increasing the reliability of expert judgment as an instrument of evidence and objectivity of engineering and technical expert research.

5. Experimental data

If, during derailment, in the pile of carriages, breakage of rails, sidewalls or other parts were revealed, even in the presence of old fatigue cracks, such breakage should not been unconditionally accepted as the cause of a disaster and accident, which is often manifested in the texts of technical statement on the event drawn up by members of the commission on official investigation of the causes of the railway accident. First of all, it is necessary to determine why supercritical power could occur, which led to the breakdown of elements of the construction of the railway transport, for example, the use of emergency braking of a train (figure 2). In most cases, such breakdowns can be both a cause and a consequence of derailment.

Therefore, a detailed study of fracture plane of part fragments gives important information about:

- whether static load exceeding limits of flow (so-called plastic fracture) affected the part (figure 3);
- whether significant impact loads, which were applied at a high speed (fragile fracture), affected the part;
- whether prolonged cyclic loading (fatigue breakdown) (figure 4) affected the part.

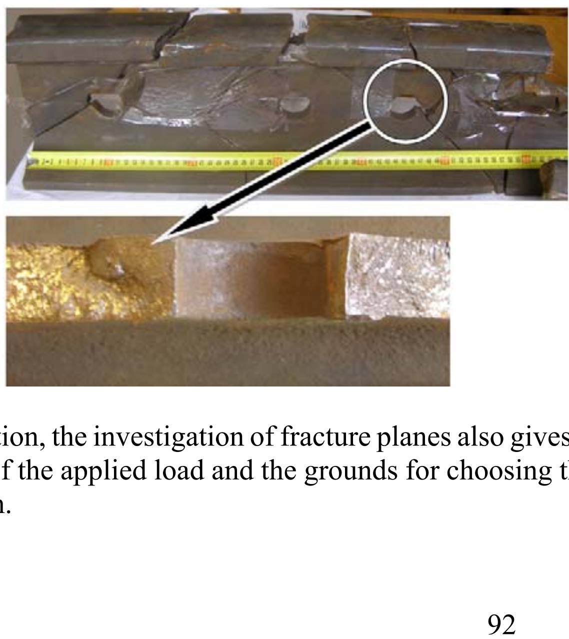

Figure 2. Rail fracture due to emergency braking of a train.

In addition, the investigation of fracture planes also gives information to the expert about the location, direction of the applied load and the grounds for choosing the method for estimating causes and time of destruction.

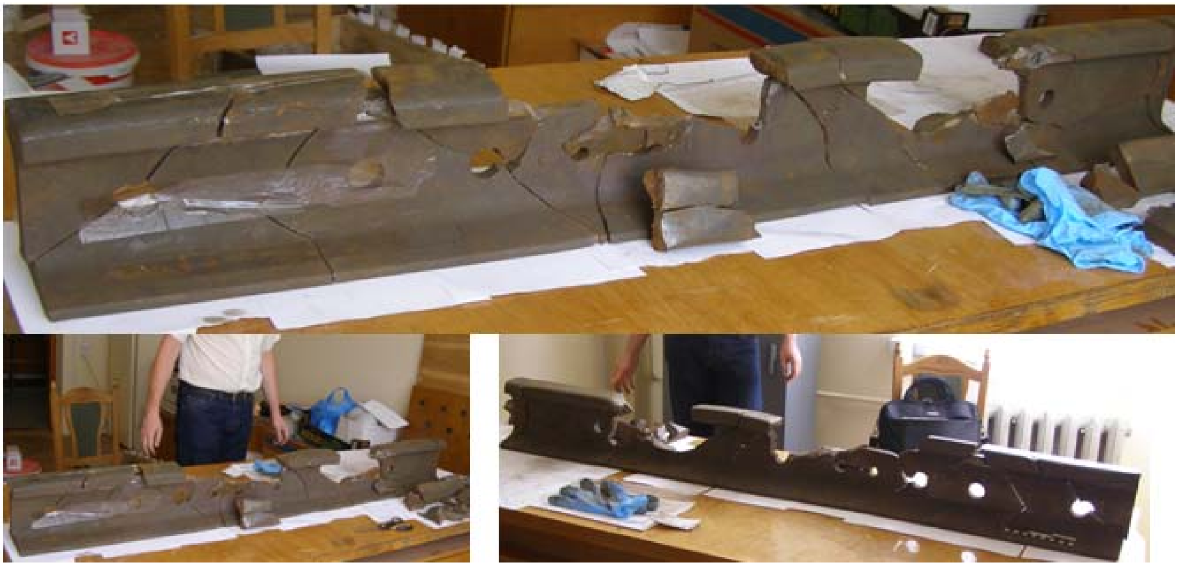

Figure 3. Fragments of plastic breakage of rail track due to the use of emergency braking of a train.

Fatigue destruction (figure 4) is characterized by the presence of the zone of origin (pos.1), the zone of gradual (fatigue, pos.2, 3) and spontaneous (uneven, pos.4, 5) crack development, and the zone of complete fracture (pos.6). Also, there is a source of destruction on the breakdown planes, which includes the microzone of the crack origin (pos.1). In turn, the zone of fatigue destruction consists of areas of selective and accelerated (catastrophic, spontaneous) crack development. The presence of such several zones indicates the change in operating conditions or change in the angle of direction of load force effect.

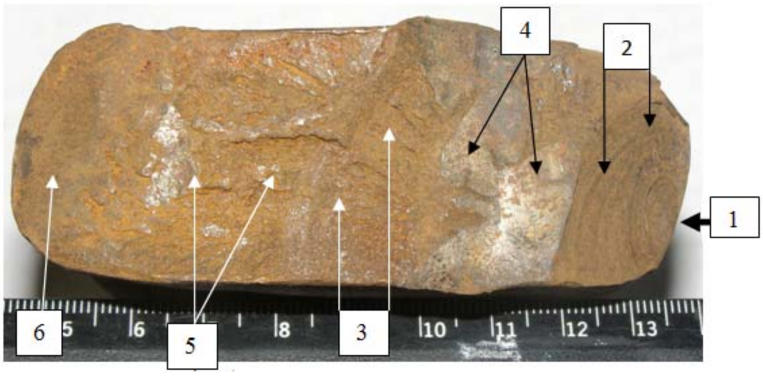

Figure 4. Fatigue fracture of the drawbar due to cyclic loading.

It is clear that non-recorded traces of damage during inspection (dints, burrs) or not saved fracture planes can be simply lost for further research. Therefore, the survey and description of the condition of the destroyed parts must be started with detailed review and recording of the entire part or a unit, considering them in the relationship as an integral element of the object of research. Particular attention should be paid to surfaces adjacent to the fracture plane, because subsequent correct and accurate expert interpretation of them depends on how far the contingent factors are eliminated that could change the characteristics of the surface of destruction. This can lead to erroneous conclusions when performing research.

Each structure has a large number of cracks of different sizes: from microscopic to macrocracks. The development of cracks takes a considerable amount of time, and the rate of crack development is very slow at the beginning of its origin and is approaching the speed of sound at the final stage. The strength of a part or a structure decreases with the development of a crack.

At the same time, during the manufacture of parts and their operation, cracks may occur, especially in areas of local tension increase, and with variable loads, in the presence of aggressive environments, temperatures and other factors that contribute to brittle fracture. The need to record all operations carried out at on-site inspection is also necessary in view of the impact on accuracy of subsequent studies. If destruction is not cut-through and further transportation is assumed, it is necessary to remove the destroyed part or unit in order to prevent damage of the fracture surface. In this case, the urgent need is to photograph objects that are related to damaged and destroyed parts, their deformation changes of the shape (figure 5).

Figure 5. Railway accident due to the breakage of the side frame of the bogie.

In view of the fact that fracture will be subject to further laboratory metal graphic analysis, a number of appropriate steps should be undertaken to obtain maximum information on the specific features of the destruction plane. The need for the committee to carry out an official investigation of the causes of a railway accident is based on the recognition that the surface of the fracture carries much valuable information about the causes of destruction. The destruction of such information by ignorance (for example, during disassembly, unskilled mapping of the fracture plane, subsequent transportation or for other reasons) may complicate or lead to an incorrect interpretation of destruction regularity or even the impossibility of conducting further reliable studies (figure 6).

Figure 6. Mapping of fracture plane of the side frame of the bogie.

Since the surface of the fracture is subject to intense corrosion, a good way of preserving the surfaces of the breakages and their protection against corrosion is the use of coatings (preservative lubricants or plastic coatings through which the surface and the fracture profile are clearly visible) that are eliminated with trichlorethylene (acetone) during further laboratory studies (figure 7). To prevent corrosive damage to the fracture plane, it is recommended to use solvents based on petroleum products, which are easily removed from the surface. It is not recommended to use a sticky tape to protect the fractures as it is difficult to remove it, and as a result of moisture adsorption, the fracture surface undergoes corrosion under it.

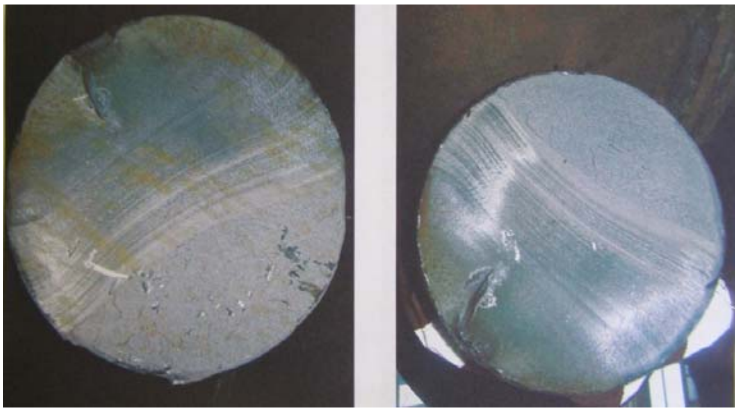

Figure 7. Fracture plane of the part, which is stored with the use of special protective coatings.

During inspection, it is important, along with identification of mechanical damage of rolling stock components, to obtain information about its general state in order to:

- differentiate defects that could exist before RTA or arise during further transportation and storage of the part of rolling stock;
- fixation of the location and size of primary or secondary damage (caused during transportation), as well as comparing it with the damage of other components of rolling stock;
- identification of traces indicating contact with other parts of rolling stock.

6. Conclusion

The proposed ways of preservation of destroyed objects directly at the scene are a set of specific knowledge that gives the persons responsible for providing destroyed objects from the scene for expert engineering and technical research, with a direct precautionary measure to avoid false conclusions and partial expert judgment.

References

[1] Magel E, Mutton P, Ekberg A and Kapoor A 2016 Rolling contact fatigue, wear and broken rail derailments *Wear* **366-367** 249–57

[2] Ju S H 2016 Study of train derailments caused by damage to suspension systems *J. Computational and Nonlinear Dynamics* **11(3)** 031008

[3] Jin Z, Pei S and Qiang S 2014 Study on derailment of railway vehicles on bridges during earthquakes based on IDA analysis *Tumu Gongcheng Xuebao/China Civil Engineering Journal* **47** 234–9

[4] Nabochenko O, Sysyn M, Kovalchuk V, Kovalchuk Yu, Pentsak A and Braichenko S 2019 Studying the railroad track geometry deterioration as a result of an uneven subsidence of the ballast layer *Eastern-European Journal of Enterprise Technologies* **7(97)** 50–9

[5] Sysyn M, Gerber U, Gruen D, Nabochenko O and Kovalchuk V 2019 Modelling and vehicle based measurements of ballast settlements under the common crossing *European Transport / Transporti Europei - International Journal of Transport Economics, Engineering and Law* **71** 1–25

[6] Sysyn M, Gerber U, Kovalchuk V and Nabochenko O 2018 The complex phenomenological model for prediction of inhomogeneous deformations of railway ballast layer after tamping works *Archives of Transport* **46(3)** 91–107

[7] Kim J H, Bae H U, Kim J W, Song I H, Lee C O and Lim N H 2018 Post-derailment behavior of casting bogie by full scale test *J. Korean Society for Railway* **21(8)** 815–29

[8] Kaewunruen S, Wang Y and Ngamkhanong C 2018 Derailment-resistant performance of modular composite rail track slabs *Engineering Structures* **160** 1–11

[9] Mirza O and Kaewunruen S 2018 Resilience and robustness of composite steel and precast concrete track slabs exposed to train derailments *Frontiers in Built Environment* **4** 60

[10] Sysyn M, Gerber U, Nabochenko O, Li Y and Kovalchuk V 2019 Indicators for common crossing structural health monitoring with track-side inertial measurements *Acta Polytechnica* **59(2)** 170–81

[11] Sysyn M, Kovalchuk V and Jiang D 2019 Performance study of the inertial monitoring method for railway turnouts *Int. J. Rail Transportation* **7 (2)** 103–16

[12] Sysyn M, Gruen D, Gerber U, Nabochenko O and Kovalchuk V 2019 Turnout monitoring with vehicle based inertial measurements of operational trains: A machine learning approach *Communications - Scientific Letters of the University of Zilina*, **21(1)** 42–8

[13] Li Q, Huang X and Huang W 2019 Fatigue property and microstructure deformation behavior of multiphase microstructure in a medium-carbon bainite steel under rolling contact condition *Int. J. Fatigue* **125** 381–93

[14] Wang Z, Han J, Domblesky J P, Li Z, Fan X and Liu X 2019 Crack propagation and microstructural transformation on the friction surface of a high-speed railway brake disc *Wear* 45–54

[15] Masoudi Nejad R, Shariati M and Farhangdoost K 2019 Prediction of fatigue crack propagation and fractography of rail steel *Theoretical and Applied Fracture Mechanics* **101** 320–31

[16] Masoudi Nejad R, Farhangdoost K and Shariati M 2018 Microstructural analysis and fatigue fracture behavior of rail steel *Mechanics of Advanced Materials and Structures* 1–13

[17] Daves W, Kráčalík M and Scheriau S 2019 Analysis of crack growth under rolling-sliding contact *Int. J. Fatigue* **121** 63–72

[18] Maneesh Kumar M, Murali M S, Saranya M, Arun S and Jayakrishnan R P 2018 A Survey on Crack Detection Technique in Railway Track *Proc. IEEE Conf. Emerging Devices and Smart Systems* 269–72

[19] Kim S, Sung D, Kang Y and Park Y 2018 Fracture mode analysis according to inclination angle of rail internal crack *J. Korean Society for Railway* **21(7)** 671–8

[20] Sysyn M, Gerber U, Nabochenko O, Gruen D and Kluge F 2019 Prediction of rail contact fatigue on crossings using image processing and machine learning methods *Urban Rail Transit* **5(2)**

[21] Panasyuk V V 1988 Fracture mechanics and strength of materials: Ref. manual: 4 tons *Science. Dumka Kiev* 225

[22] Khyl V, Rudavskyi D, Kanyuk Yu and Sas N 2018 Determination of the period of subcritical growth of internal cracks in the rail head under operating loads *Materials Science* **53(6)** 80–7

[23] Datsyshyn O 2005 Service life and fracture of solid bodies under the conditions of cyclic contact interaction *Materials Science* **41(6)** 709–33

[24] Kaminsky A 2014 Mechanics of the delayed fracture of viscoelastic bodies with cracks: Theory and experiment (Review) *International Applied Mechanics* **50(5)** 485–548

[25] Guz A, Guz I, Men’shikov A and Men’shikov V 2013 Three-dimensional problems in the dynamic fracture mechanics of materials with interface cracks (review) *Appl. Mech.* **49(1)** 1–61