The life cycle assessment of the used rails according to the results of cyclic high-frequency tests

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Abstract: The article presents the results of the strength tests and the metallographic studies of used rails with the significant running surface wear. On the basis of the accelerated modeling of the continuously welded rail life cycle, an assessment system is proposed to evaluate the life cycle of the used continuously welded rails that are sent to the rail repairing depots.

1. Introduction

On operating, the rails are exposed to a variety of loads which lead to plastic deformation of the metal and the development of different irregularities on the running surface of the rail head; the occurrence of internal and surface defects and their further development; the change in the internal stress state of the rails that causes significant changes in the service properties of rails.

Nevertheless, most of the rails that are replaced for the overall track repair of the first and third levels have an inexhausted capacity for work. After appropriate sorting and repair, such rails can be reused on less busy sections of the main lines and the tracks of the industrial railway transport. According to the present time standards, the service life of the used rails, before they should be finally replaced, is about 60 % of the first service life after new rails have been laid [1-4].

The service life of re-laid used rails depends on the initial tonnage passed on them. When the first term of tonnage passing exceeds the standard term, the rails begin to fail soon after re-laying. The major number of rails - 75-95 % is removed due to the defects of contact-fatigue character, that are developed during the first service life and are not detected during the repair and re-laying [6-7]. These defects seriously limit the second life of the rails.

The increase in the tonnage operating time on the rails is accompanied by their wear and the accumulation of fatigue damages in them, causing the development of the following defects [8-10]:

- metal wear and violations of the straightness of the rail head running surface in the longitudinal direction, manifested in the form of the corrugated wear and isolated irregularities, slips, saddles in the welded joints, crumpling of the rail ends, etc. The occurrence and development of these defects result in great additional dynamic loads on the track and then, they result in an intense disorder of the track;
- cold hammering in the surface metal layer of the rail head, increasing as the working tonnage grows; leads to the development of microcracks and macrocracks and metal painting;
- internal longitudinal and then transverse cracks of the contact-fatigue nature develop in the depth of 3-12 mm in the operating fillet of the head;
- the defects and damages, located in the web and base of the rail: the cracks in the web and base in the form of corrosion, wear, indent, etc.

2. Methods

To provide the safety of train traffic at all stages of the rail life cycle, one should be able to predict the rail failures.

This article presents the study of the used rail fragments in order to determine their residual operation time based on the results of accelerated modeling of the life cycle of the continuously welded rail with the further research of the changed microstructure of steel.

The assessment of the used rail condition begins with the identification of the necessary samples near the places, where the rail parts are cut out of the continuously welded rails, then the assessment is carried out in the specialized laboratories.

The acceptance control of the used rails, the welded joints of rails and the switch elements is done according to the technological control instructions for a specific type of non-destructive testing tool. The research of the samples from a continuously welded rail fragment before its destruction is also carried out. This type of control is recommended to be used selectively at the rate of one primary sample per 10 continuously welded rails, removed from the track. The primary sample, cut off from the end of the continuously welded rails and the example of each is shown in Figure 1, is used to produce three samples from the rail head (III) and the rail base (I) and two samples from the rail web (II).

The acceptance of the welded joints from the manufacturer is carried out at the manufacturing company with the help of x-ray analysis, meanwhile, the welded joints, welded into a single track, are tested with the help of the acoustic emission method.

![Figure 1. The schema of the primary sample division.](image)

Having prepared the samples, tests and studies are carried out according to the following schema:

1) Cyclic high-frequency tests are carried out with a symmetrical loading cycle ($R = -1$) on an ultrasonic unit. For the experiments only those samples are taken that have the shape of a rotation body with cylindrical ends and the middle part, which is an arc of a large radius (figure 2). During the test, the sample is put into the resonant vibrations with a frequency of up to 20 kHz. The test ends up when the sample goes out of the resonance due to the structural changes.

The modes of high-frequency tests are recorded in table 1, where $\Delta a$– the amplitude of the stress cycle.
When marking and identification information of the studied rail part are interfered, first of all, it is necessary to conduct a chemical analysis of the metal and to carry out some static tensile tests to determine the main mechanical characteristics. The conducted studies will allow to identify the element that the study is focused on. The study results are recorded in the special table according to the percentage of the elements in the main and malting metal (if the sample contains a welded joint of the continuously welded rail).

2) The test of microhardness. There is a special method for measuring microhardness which involves the usage of an automatic microhardness tester (the test time of one sample takes 50 hours of the continuous operation). Microhardness is measured across the entire width of the sample - from its center to the shank with a step of 100 mkm, and at a distance of 1000 mkm from the center, the step was increased to 500 mkm. This method allows to identify the location of increasing microhardness, which can become stress concentrators and affect negatively the material during the subsequent loading. According to the obtained results, a special table (Table 2) is filled in and graphical dependencies can be drawn to converse subsequently the values of the strength parameters from the micro- to the macro level.

Table 2. The results of microhardness measurements of the sample according to the sections.

| Sample center | Average value of microhardness |
|---------------|--------------------------------|
| 389 HV 376 HV 366 HV 355 HV 366 HV 375 HV – | 359,8 HV |
| 382 HV 366 HV 407 HV 389 HV 359 HV 357 HV – | – |
| 400 HV 377 HV 367 HV 349 HV 405 HV 355 HV – | – |
| 407 HV 341 HV 343 HV 368 HV 379 HV 377 HV – | – |

200 mkm from the center

| Sample center | Average value of microhardness |
|---------------|--------------------------------|
| 318 HV 384 HV 357 HV 348 HV 437 HV 392 HV 347 HV | – |
| 365 HV 370 HV 393 HV 377 HV 415 HV 363 HV – | – |
| 342 HV 372 HV 353 HV 412 HV 373 HV 390 HV – | – |
| 363 HV 355 HV 376 HV 413 HV 357 HV 377 HV – | – |
400 mkm from the center

| Hardness | 395 HV | 358 HV | 362 HV | 355 HV | 379 HV | 396 HV | 415 HV |
|----------|--------|--------|--------|--------|--------|--------|--------|
| Location | 416 HV | 393 HV | 359 HV | 356 HV | 348 HV | 399 HV | 390 HV |
|          | 378,4  |        |        |        |        |        |        |
| Location | 357 HV | 381 HV | 393 HV | 367 HV | 386 HV | 412 HV | –      |
|          | 356    | 348    | 379    | 399    | 390    | 396    | 415    |
| Location | 365 HV | 345 HV | 376 HV | 368 HV | 363 HV | 405 HV | –      |

Hardness of the heat treat rails should coincide with the values, given in Table 3.

3) Metallographic studies (optical metallography) make it possible to assess the sample microstructure and its changes (the development of a white layer), to identify the internal defects and stress concentrators, as well as possible causes of the failure – the development of microcracks under the influence of high-frequency vibrations. Moreover, we can predict the appearance of the internal defects.

**Table 3. Hardness of the heat treat rails, HB.**

| The location of hardness determination | Rail hardness for the category |
|----------------------------------------|-------------------------------|
| On the running surface of the rail head | B, T1, T2                     |
| 10 mm below the running surface        | 363-401, 341-401, 321-401     |
| 20 mm below the running surface        | 341, 341, 321                 |
| In the web and base of a rail          | No more than 388              |

The most loaded part of the sample is prepared for the study. As a rule, it is the rail web with the length of 27±1 mm. The preparation undergoes several stages: cutting, pressing (in acrylic resin to ease fixing of the samples on the equipment), grinding – polishing and etching.

4) Electron microscopy of the selected samples is conducted at magnifications of 5000× and 25000×. The images allow to assess the structure of perlite at various points of the rail cross-section, to identify the location of the failure and the state of grains.

The conducted research is drawn up as a report of the specialized laboratory that has the appropriate laboratory equipment, software and hardware equipment, and the personnel with the valid qualifications.

The report based on the results of the high-frequency tests should contain:

- The assessment of the failure possibility with the appearance of a "white layer", when its microhardness exceeds 1000 HV, under the combined impact of the high-frequency vibrations and the real amplitudes (800 MPa), interacting in the wheel-rail system.
- The focused measurement of microhardness in the crack zone at the range of amplitudes of 770-700 MPa and lower (welded joints).
- The assessment of the possible accumulation of the damages leading to destruction.
- The number of loading cycles, under which no structural changes have been detected.

The control based on the above mentioned procedure should be conducted before setting the used rails into the track and welding them continuously, while the primary samples present the segments of rails from the beginning and the end of the segment (one rail per 25 delivered rails), as well as the section of the welded joint (one sample per 50 welded joints of 20 cm long). The primary sample is delivered to the specialized laboratory and then secondary samples are made from it to be used for static and dynamic tests: three samples from the head and the base rail part and two samples from the rail web. To measure microhardness, a sample from the middle rail part or from the zone near the failure is cut out from each secondary sample.

In addition to high-frequency tests, the welded joints are studied with the use of the X-ray analysis (on primary samples cut out from the used rail) at the rate of one primary sample per 5 joints. If the
welded joint is not included into the primary sample for high-frequency tests, it is tested with the help of the acoustic emission method at the rate of one sample per 20 joints.

3. Conclusion
The issues connected with the proper usage of the used rails that are laid into a distance-based limit, and with the replacement of the defective and acute-defect rails in a single order, are especially important on the sections with the overpassed tonnage, since the share of such used rails in the total single removal of the first laying rails is ranged from 7 to 34%.

In 36% of cases, the service life of the used rails laid in a single order on the load-stressed directions does not exceed 100 mln. tons of gross, in 18% of cases — less than 50 mln. tons of gross. The major amount of rails 75-95% is removed due to defects 10, 11, 13, 21, 30, developed during the first term of the life cycle and which are not detected during the repair and relaying.

An important parameter that allows to assess the possible reuse of the rail is the number of dynamic loading cycles that the prototype can withstand before it failures under high-frequency impacts, the value of microhardness after high-frequency tests of the prototype, the specific values of which are calculated with the help of the method mentioned above.

Carrying out the proposed control of the used continuously welded rails will allow to control the risk of pre-defect condition. Besides, the proposed method can be used as the addition to the method of operational rail testing and the statistical analysis of the rail life cycle on the lines of JSC "Russian Railways".

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