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RAIL AND RAIL WELD TESTING

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Abstract: Quality of rails and rail welds *plays a significant role in railway safety and general functioning. Testing of rails and rail weld plays a major part in quality control for rails and rail welds.*
Testing of rails is regulated by relevant standards, regulations and legislations. The testing of rails and rail welds is directly linked to the quality assurance programs of the railway entrepreneurs or the rail welder company.
Key words: rail; testing; standards; rail welds.

1. INTRODUCTION

Quality of rails and rail welds plays a significant role in railway safety and general functioning. Testing of rails and rail weld plays a major part in quality control for rails and rail welds. Railway safety is also closely linked to the quality of joining the rails by welding, which is directly linked to the quality assurance programs of the railway entrepreneurs or the rail welder company. Testing of rails and rail welds are regulated by relevant standards, regulations and legislations.
Choosing the right test parameters is vital for adequate test results. The standards are not always the only source when choosing the test parameters, relevant test standards can be supported by research results to choose the right test parameters.
With the arrival of the new USA locomotives, which have a greater load per axle than the old Russian ones, and due to the increased rail heavy haul traffic the rails are subjected to even greater stresses and are more likely to break as a result.
The costs of a rail accident are high and may have long time effect on the credibility of the railway entrepreneur.
The main objective of the study is to review the main requirements for rails and rail testing, which can be obtained from the relevant standards, which give the reference values for testing or from individual specific requirements for a country.

2.RAILS

Rail main function is to withstand the loads and guide the rail cars. Due to the harsh working environment rail has to withstand corrosion, heat changes, and withstand cyclic loads. All this leads to rail wear and to a possible rail failure. Also the rail has to be machinable and weldable. To reduce the rail wear some of the rails are hardened either only from the head or the whole rail (EVS EN 13674-1; GOST R 51685-2000)
Rail steel is commonly carbon- manganese steel with mostly pearlitic microstructure. The methods used to make the steel for rails vary between the oxygen furnaces and more moderns electric-arc furnaces with vacuum degassing to remove hydrogen and oxygen and other gases from the molten steel from. The hydrogen is most likely to cause cracks in the rail head (Sperry Rail Service, 1999; D.F. Cannon et.al., 2003).
For making the blooms either ingot or continues casting methods are used.
The chemical composition, tensile strength and hardness values differ with the different grades of rails. All in all there are 7 grades including non heat treated carbon manganese, non heated alloy (1%Cr), heat treated carbon manganese and low alloy steels in the European standard and 11 grades in the Russian standard. In the table 1 is shown the chemical composition of grade R350HT and Э76T steels that are mainly used to for new railway lines in Estonia. The rails profiles used are in Estonia are European 60E1 and Russian P65, P50 and P43.

Table 1. Chemical composition of grade R350HT and Э76T

C, %	Si, %	Mn, %	P, %	S, %
R350HT				
0.72…0.80	0.15…. 0.58	0.70…1.20	0.020	0.008…0.030
Э76T				
0.71…0.82	0.25…0.45	0.75…1.05	0.025	0.030

2.1 Rail steel defects

Rail failures can be divided into three main groups:
- the rail manufacturing defects e.g. hydrogen cracks;
- defects due to the inappropriate handling, installation and use;
- defects caused by the exhaustion of the rail steels inherit to resistance to fatigue damage (D.F. Cannon et.al., 2003).

Due to the harsh working environment rails are susceptible to failure. In addition to bending and shear stresses rails have to withstand dynamic loads and contact, thermal and residual stresses. The contact stresses between the wheel and rail are high, up to 4000 MPa routinely and up to 1500 MPa with axle loads up to 37 t and contact are between the wheel and rail around 1 cm^2 (D.F. Cannon et.al., 2003;Telliskivi, T et.al.2000).
The flattened wheels and also irregularities in the surface condition of the rails mostly cause dynamic stresses.
Thermal stresses are cause by the change in the weather temperature, in Estonia that could be in the range of -25ºC…+30ºC.
Residual stresses are introduced into the rail during the straightening process during manufacturing.
Majority of rail failures are due to the transverse defects caused by the either rail inner defects such as inclusions or fatigue cracks (D.F. Cannon et.al., 2003; Skinner,D.H.;Judd P.A., 1981).The main reason for forming inner defects is hydrogen and oxygen. The hydrogen can hydrogen cracks within the steel that can lead to formation of kidney shape transverse defects upon traffic. Vacuum degassing and control cooling is used to extract gases (Sperry Rail Service, 1999).
For determining the sulphur segregation sulphur print method is used. Sulphur is the main cause of non-metallic inclusions in rail steel that could form a transverse crack, especially when clustered together. The critical size of the inclusion was shown

to be about 80 μm and more for initiating a transverse fatigue defect. For forming a transverse defect larger inclusion diameter is needed (Skinner,D.H.;Judd P.A., 1981).
The microstructure of the rail steel is supposed to be pearlitic, no martensite, bainite or grain boundary cementite is allowed.

Such high stresses and cyclic loading demand the rail steel to have adequate mechanical properties e.g. tensile strength and elongation, fracture toughness, hardness, fatigue crack growth rate and also impact strength.
Requirements for rail steel are given in the European standard EVS EN 13674-1.

2.2 Rail testing according to EVS EN 13674-1

Rail steel testing is usually done as a part of rail manufacturing process following the quality management system of the manufacturer.
To assess the lifetime of rails the fatigue crack growth rates must be known, to predict the crack propagation, the Paris law $da/dN = C(\Delta K)^n$ is used to characterize the fatigue crack growth rates. Fatigue crack growth rate tests are carried out according to the requirements of the BS 6835-1, a three-point bend and single edge notch test piece shall be used, with stress ratio should be kept at 0.5. (L F M da Silva et.al., 2003)

Fatigue testing are carried out according to ISO 1099 with symmetrical cycle about the initial zero load. The qualifying criterion is for total strain amplitude of 0,00135 is minimum of $5x10^6$ cycles.

Hardness tests are conducted on the running surface of the rail and on the cross section of the rail for the heat-treated rails. The preferred hardness testing method is Brinell hardness according to EN ISO 6506-1 with test load of 1.839 kN and 2.5 mm diameter tungsten carbide ball indentor.

Tensile tests are carried out on round specimens with diameter of 10 mm and gauge length of 50 mm from the railhead crown. Tests are carried out according to EVS EN 10002-1

Fracture toughness (K_{Ic}), the tests are carried out according to ASTM E399 with specimen thickness of 25 mm and width 40, 45 or 50 mm. The test temperature is -20ºC ± 2ºC.

Chemical composition tests are to determine if the steels conform to the requirements of EVS EN 13674-1.

Impact testing is not foreseen in the new European rail standard, but it does give information about the degree of toughness in lower temperatures. (Kecskes, S et.al., 1996).
The European standard also gives requirements for rail profiles, dimensions, straightness, surface flatness and twist.

3.WELDING METHODS

The two main welding methods used for joining rails are: thermite welding (TW) and flash welding (FBW). FBW is used to join the short about 25 m rails to about 150 m rails which are then shipped to the site and joined together by the TW to produce continuous rails.
Out of the two welding methods used the thermite welds are more likely to fail due to their microstructure and cast defects similarly to cast steel. About 17% of rail failures occur on TW in comparison 7.9% in FBW (D.F. Cannon et.al., 2003).
The greater number of failed TW welds is due to the microstructure and macrostructure e.g. sulphur segregation formed and also the chemical composition of the weld is different from the rail the carbon content is smaller but the Mn-, Si-content higher and also there is some Al present. The microstructure of the FBW weld is mostly pearlitic with some ferrite and the TW the bead microstructure is bainitic and in the heat affected zone coarse-grained pearlite. As a result weld bead can be harder or softer then the rail material and cause uneven wear in that area, whish leads to the increase of noise and stresses in rail. With the FBW welding the hardness change in the heat affected zone is not significant. The thermite weld heat influence zone is wider then in the case of the FBW.
The temperature of the TW welding process is higher then the FBW welding about 2300-2400°C and 4000-5000°C accordingly. (Kecskes, A; Kiss, Saba, 1996).
The mechanical properties of the TW welds can be improved by a heat-treating. The main influence of the heat-treating is making the coarse ferritic-pearlitic microstructure into much finer structure but the hardness of the heat-affected zone decreases which in not favourable. The heat treatment for a UIC 860 S49 type of rail was suggested to be a heating the weld up to 840 ºC holding the temperature for 45 minutes and air cooling (Ilic, N et.al., 1999).

3.1 Rail weld tests

The first test after the welding is visual examination of the weld for visible defects such as geometry, and is usually carried out by the welding personnel on sight. The tests carried out in the laboratory are hardness test, slow bend test, fracture surface examination, micro- and macro structure examination.
Test methods for both TW and FBW welds are similar and the requirements for thermite welding process are given in pr European standards EN 14730-1 Railway applications. Track. Aluminothermic welding of rails. Part 1: Approval of welding processes.
The requirements for flash butt welding process are given in pr EN 14587-1 Railway applications. Track. Flash butt welding of rails. Part 1. New 220 and 260 grade rails in a fixed plant, pr EN 14587-2 Railway applications. Track. Flash butt welding of rails. Part 1. New 260Mn and 350 HT grade rails in a fixed plant.

3.1.2 Rail weld hardness tests

Hardness tests are to show the distribution if hardness in rail base material, weld and HAZ. The hardness test is the easiest way to estimate the quality of the rail weld in the first approximation. By it's own it cannot be used to determine the quality of a weld and usually it is complementary to other test methods discussed here. The hardness numbers are to illustrate the type microstructure of the weld and HAZ.
According pr EVS EN 13674-1hardness tests include Vickers HV30 to determine the distribution of hardness values of the weld and HAZ and HBW 10/3000/15 to determine the weld hardness on the centre line of the head crown.
According to ANSI/AWS D15.2-94 a Rockwell hardness suggested to determine the hardness traverse on a vertical central longitudinal section plane, and Brinell 10/3000 on the head, it seems that the Vickers method gives better resolution of the hardness traverse due to the fact that the indentations can be made more close to each other then the Brinell method would allow.

3.1.3 Rail weld bend tests

Rail bend test is carried out to determine the quality of the rail weld by the means of examining results of the static bending test.
Rail is either bent to some qualifying criterion load or to break. After the rail fracture the fracture surfaces are examined for macrostructure e.g. visual defects such as inclusions, lack of weld.
For both thermite and flash butt weld the test scheme is the same according to pr EN 14730-1 and pr EN 14587-2, 3-point bend test (fig.1).
The maximum loading speed is 1 mm/s. The parameters measured are load at break and maximum deflection.

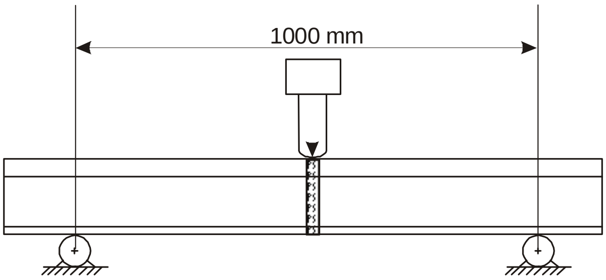

Fig.1 Bend testing scheme

According to ANSI/AWS D15.2-94 the span length is 1200 mm and loading instead of 3-point bend scheme a 4-point loading scheme is suggested to be used (fig.2).
The load is applied at two loading points 300 mm apart. Load is applied until the rail fractures or deflects 100 mm, which ever comes first.

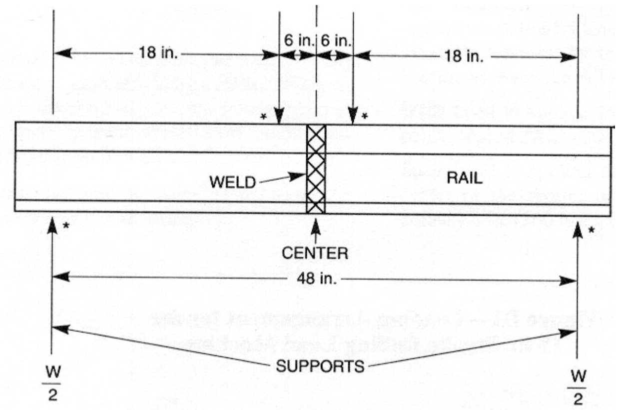

Fig.2. 4-point bend test scheme suggested by the ANSI/AWS D15.2-94

3.1.4 Rail weld fatigue tests

Rail fatigue testing is carried out, accordingly to pr EN 14730-1 in the case of TW and pr EN 14587-1 in case of FBW, on a rail weld with a 4-point type of bend test scheme
The qualifying criterion for cyclic load is, with ratio min/max load ratio of 0.1 and frequency of 10 Hz, a minimum of $5x10^6$ cycles.
According to ANSI/AWS D15.2-94 the rail weld fatigue testing is suggested to be carried out by rolling load test scheme. Test speed is 60 cycles per minute (1Hz) for total of 2 million cycles or to the failure which ever comes first (fig.3).

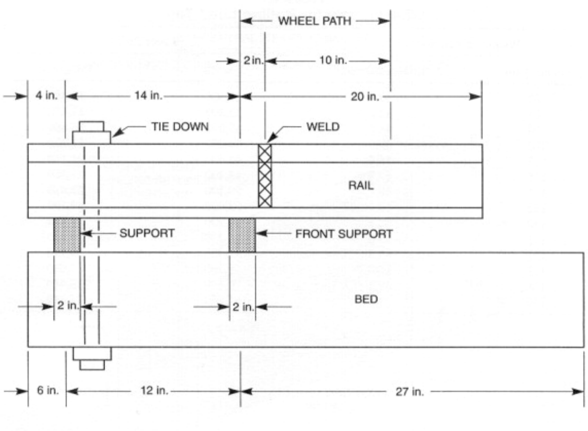

Fig. 3 Rolling load test scheme suggested by the ANSI/AWS D15.2-94

5. CONCLUSION

The main rail mechanical testing methods for rails and rail welds were reviewed.
Rail testing is closely linked to the relevant standards and testing methods. When choosing the test parameters for some of the standard test methods, it is advisable to consult the relevant articles for the preferred test parameters and guidelines.
The increase of heavy haul rail traffic in Estonia has raised the need for rail testing. The testing is carried out according to the relevant European standards.
In addition to rail testing monitoring the roundness of the rail-car and locomotives wheels is important to reduce the dynamic shock loading of rails. Also monitoring the state of the embankment is important to reduce the possible affect of the additional stresses to the rails.

6. REFERENCES

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