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Residual Stress Measurement in Rails

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Abstract

Measurement of residual stress in rails for track designers has assumed great importance in recent years. This is because of higher axle load, increased traffic density and faster speed of trains. There are several ways of measurement of residual stress depending upon the method of testing used. Some of the important ones are X-ray method, Barkhousen noise method, Acoustic emission method and Strain Gage method.

Regular measurement of residual stress in rails by the Strain Gage method is performed at the Stress Measurement Laboratory of RDCIS, SAIL at Ranchi. Strain Gage based template cutting and blind hole drilling method has been adopted for this measurement. In laboratory scale study, transverse template cutting method is being used to determine residual stresses in 52 and 60 kg rails of 90 UTS grade produced through the LD-CC route. It has been observed that both 52 and 60 kg rails have similar residual stress patterns. The highest stress level is observed at the foot centre of rail and its nature is tensile. This residual stress pattern is also found to be almost similar in case of gag pressed and straightened rails.

Keywords: *Rail, Residual stress, Semi-destructive test, Strain gauge, Straightener*

1. Introduction

Residual stresses in rolled products are generated due to uneven cooling after hot rolling and also during finishing operations, such as roller straightening / leveling. Development of these stresses on the surface and inside the rolled products has serious implications for fatigue damage in service applications. Residual stress is often described as “Silent Killer”. A member designed to fail at a certain stress can fail at a much lower stress as the residual stress component is added to it. The deleterious effects of residual stresses in a member are usually observed only after external loads or environments are introduced, such that the combined effects cause noticeable damage. Residual stress, significantly influence the structural and dimensional stability as well as the life span of different rolled products like rails. Residual stresses combined with external static and dynamic loads may cause catastrophic premature failure of rails, which leads to high casualties and loss of property.

2. Techniques for Measurement of Surface Residual Stress

Residual stress measurement techniques at the surface of different materials can be broadly classified into 3 types viz.- *Destructive* method, *Semi-destructive* method and *Non-destructive* methods.

2.1 Destructive Method

A portion of the residually stressed body is cut away and the resulting deformation of the body is carefully measured with the help of strain gages, then the residual stresses, which existed at the freshly exposed surfaces, before they were thus exposed, can be calculated. This technique called dissection method is, though old, still powerful. The disadvantages of this technique are: the method is very tedious and painstaking, theoretical analysis is difficult and the method is unable to detect residual micro stresses.

2.2 Semi-destructive Method

Hole drilling method is a widely used method for measuring residual stress. It involves the drilling of a hole on the surface of the object being examined, and the measurement of strain redistribution that takes place on the surface as a result of the hole. Elasticity theory is used to calculate the residual stresses that existed prior to the drilling. The strains may be measured with strain gages or with photo-elastic coatings mounted on the surface before drilling. In principle, Moiré grids or optical holography could be used but this would necessitate the added step of converting displacement measurement to strains. The most commonly used technique of this kind employs a special purpose three element strain gage rosette and a rigidly guided milling cutter that is used to drill a straight, circular, flat-bottomed hole at the center of the rosette, normal to the surface. The deficiencies of this method are: Measurements are taken at number of points which is time consuming, milling guide cannot always used when the surface is not flat (corrections for off-center holes have been proposed for this factor), the drilling operation may introduce other residual stresses (drilling hole by air abrasion technique is used to avoid this), plasticity effects make it difficult to measure residual stress beyond 70% of yield stress. A standard recommended practice for this method has been developed by ASTM.

2.3 Non-destructive Method

These are basically of three types as given below:

X-ray Diffraction method is most widely used non-destructive method for evaluating residual stresses. It is based on lattice strains, the changes in the spacing between crystallographic lattice planes, which are caused by stress. The disadvantages of this method are: as the volume of surface material interrogated by the x-ray beam is small, and the lattice strain which is measured reflects the combined influence of both micro- and macro-residual stresses acting at that location. In materials having high variation of micro-stress gradients the evaluation of macro-residual stress is not proper. The elastic constants of crystals vary with their orientation so that their calculated values differ substantially from the measured values; measured values are not always available.

Ultrasonic Method for evaluating residual stresses are based upon the changes in the velocities of ultrasonic waves due to stress. The disadvantages of this method is: higher order elastic constants are generally required in order to relate ultrasonic velocities to residual stress. These constants which are also dependent on the metallurgical texture must be experimentally determined for a particular material being examined, this method has a limited capability for detecting sharp stress gradients and it has little use for determining residual stress in materials such as plastics, composites and certain nonmetallics.

Barkhausen Noise method now-a-days is considered a very popular method for determination of residual stress. When a ferromagnetic material is subjected to a magnetic field it becomes magnetised in a rapid series of tiny steps or jumps. These discontinuous changes may be monitored with sensitive electromagnetic or acoustic detectors. The measured signals, called "Barkhausen noise" are influenced by the residual stresses in the material. Under alternating magnetic field repetitive noise patterns may be obtained. The disadvantages of this method are: a theoretical relationship between Barkhausen noise and residual stress is yet to be established and the use is limited to ferromagnetic materials.

3. Methodology of Residual Stress Measurement Adopted By RDCIS

3.1 Principle

Several methods are available for the measurement of residual stress in rails. However the method adopted by RDCIS is known as the "Transverse Template Cutting Method". In this method a sample of one-meter length is taken from the rail. A slice of 50-60 mm thick is cut in the center of the sample. Stresses in the slice are measured before and after cutting. The difference of two measurements gives residual stress in the sample.

The stress σ is calculated as given below:

$$\sigma = E\varepsilon \qquad (1)$$

Where,

E = 2.06 x 10^5 N/mm^2

ε = Measured value in $\mu\varepsilon$ ¸ (micro-strain)
$\sigma = \varepsilon$, x 10^{-6} X 2.06x10^4 kg/mm^2
$\sigma = \varepsilon$, x 2.06x10^{-2} kg/mm^2

3.2 Procedure

Samples of one-meter length are cut from the rails leaving 2 meters from theend. Surface of the sample is rubbed with fine grinding stone and emery paper. Special care is taken while rubbing so that the surface of the sample should not become hot. Marking on the surface profile is done with the help of the surface plate and height gauge marker. Very faint marking is done so that residual stress does not get released during the marking process. After marking of the sample the surface is cleaned with CTC (Carbon tetra-chloride) & acetone. After cleaning the working part of the sample is flush washed with degreaser and the working area is cleaned with dilute phosphoric acid solution to remove rust and other dirt particles. An alkaline solution is now applied on the sample surface and then cleaned with a neutralizing agent. A surface conditioner is then applied on the surface to ensure proper adhesion of the strain gauge. The strain gauges are fixed with pressure sensitive adhesive known as M-Bond 200. Once curing of the adhesive is completed, connecting wires are soldered with strain gauge and terminals. The installation testing is now done after which the strain gauge connecting wires and terminals are painted with protective coating to protect the strain gauges from corrosion.

The strain is now measured by using strain balancing bridge and digital strain indicator. This measurement is taken as zero strain. Fig. 1 shows the set up for strain measurement.

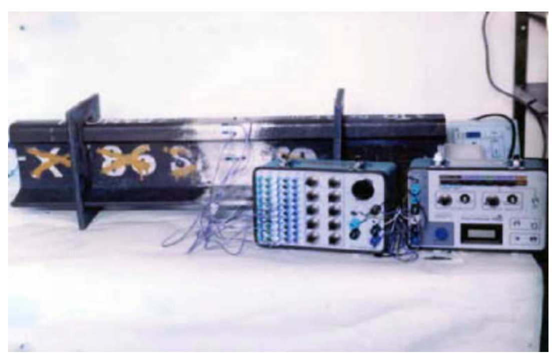

Fig. 1: Experimental set up for strain measurement

The sliced sample is now disconnected and cut as shown in Fig 2. Proper coolant should be used to avoid any heat generation during the process.

After cutting of slice, strain is again measured with the above-mentioned set up taking proper care such that there is no disturbance made to the set up. This reading of the indicator gives strain in Micro-Strain units. The final measurement of strain is performed in a set up as shown in Fig 3.

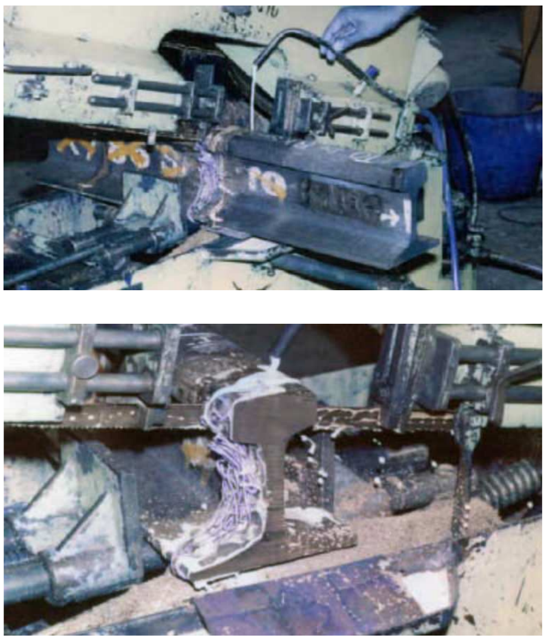

Fig. 2: Method employed for Sample Cutting

Fig. 3: Experimental set up for final Strain Measurement

Once the strain is measured, it is possible to calculate the Residual Stress with the formula given in Equation 1.

4. Conclusion

Out of several methods available for measurement of residual stress, the “Transverse Template Method” employed by RDCIS is easy and very accurate method of residual stress measurement. Indian Railway has accepted this method for quality criteria test of rail and this test is done for them as regular and routine basis. Measurement of residual stress has been done for more than five hundred rails samples with different parameters of cooling and straightening and different magnitude of camber.