Assessment of fatigue crack length of rail steels

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Abstract. This paper is to discuss the principle of fatigue crack length behaviour. The fatigue testing method was done at Physical Metallurgy Lab of Research & Development Centre for Iron and Steel (RDCIS), SAIL, Ranchi to know the utilization of fatigue properties of RAIL STEELS. Samples were produced by SAIL at Bhilai Steel Plant. In addition to the fatigue test, other tests including hardness, metallographic and EDS were also conducted. After the fatigue test, fractured surface were also observed under scanning electron microscope (SEM) to understand the mode of fracture and any stress raiser such as inclusion or other imperfection present.

1. Introduction

Fatigue testing predicts the in-service life of materials. In the beginning of the nineteenth century, engineers were shocked because of the failure of the some mechanical components below the tensile strength of the materials. They were puzzled that a component made from a ductile material could fracture in a brittle manner. They found that there was no defect in workmanship or material. The stress imposed on the material was not steady in magnitude but varying in a cyclic manner. This kind of failure of a material by varying stress cycles became known as fatigue.

B.O.Caglayan et al.,[1] studied the Marmaray project of Istanbul in which two continents Europe and Asia were to be connected by using an underwater link. The project also investigated the existing steel railway bridges and evaluated the fatigue life. B.Lennart Josefson et al.,[2] described the risk in the weld zone of rail to know crack initiation in rail head and web. Ozden Caglayan et al.,[3] studied the crane runway girders of a steel mill structure and its fatigue life. Boulent M.Imam et al.,[4] investigated the riveted stringer to cross-girder connections and its behaviour to get its fatigue life. J.E Gamham et al.,[5] studied the pearlitic steels and its metallurgical characterisation of small cracks and on the basis of twin disc test, assessed the rolling contact fatigue life. R.Jones et al.,[6] investigated the crack length vs. cycles for high strength aerospace steel, several aerospace quality aluminium alloys and several rail wheel steel which was given the load of constant amplitude. S.Maya-Johnson et al.,[7] investigated the fatigue crack growth rate of two pearlitic rail steels. Hyun-Kyu Jun et al.,[8] determined the cause of fatigue failure and the effect of residual stress on crack growth rate by conducting failure analysis and crack growth analysis on a fractured weld repaired rail. Lewei Tong et al.,[9] investigated the steel reinforced concrete beams, conducted the fatigue testing and identified the factors which influence the fatigue strength of steel reinforced concrete beams. Daniel F.C et al.,[10] studied the fatigue crack growth behaviour of the steel in mode I, mixed mode I-II and also evaluated the crack path starting from an assumed flaw for a Spanish AVE train wheel.
2. Experimental Analysis

The configuration of sample used is shown below in the fig 1. Sample made of 45mm width, 180mm length and 25mm thick with initial crack lengths of 24.93mm, 24.70mm, 24.57mm and 25.22 mm respectively. The mechanical properties of the steel sample are given in the below table 1. In this way, four test specimen having different frequencies 16, 18, 20 and 22 Hz respectively were tested.

![Configuration of the specimen.](image)

**Figure 1.** Configuration of the specimen.

**Table 1.** Mechanical properties of the sample.

| YS (MPa) | UTS (MPa) | Elongation (%) | Hardness (BHN) |
|----------|-----------|----------------|----------------|
| 700      | 1029      | 13             | 300            |

![Fatigue testing machine.](image)

**Figure 2.** Fatigue testing machine.

Fatigue testing is done with the help of digitally controlled servo hydraulic 100kN dynamic testing machine, model instron 8801 shown in the figure 2.

During the fatigue test we have applied the cryogenic conditions to break each sample into two parts. In cryogenic conditions, samples are cooled by liquid nitrogen to a very low temperature about -120 C. Again, we cut each sample into two-piece, one being the fractured surface and the other non-fractured surface. Take the small piece of fractured surface and clean it by using Acetone and go for ultrasonic for 10 minutes to remove all the dust particles and contaminations. Scan that piece by using Scanning Electron microscope (SEM) and get the microstructure of it.

![Cut sample.](image)

**Figure 3.** Cut sample.

3. Results and Discussion

3.1 Microstructure of the fractured surface
Microstructure has been taken from the 3 portions, marked as 1, 2 and 3 of each fractured-surface having frequencies 16, 18, 20 and 22 Hz respectively.

![Microstructure images](image1)

**Figure 4.** Microstructure of fractured surface at portion 1.

![Microstructure images](image2)

**Figure 5.** Microstructure of fractured surface at portion 2

![Microstructure images](image3)

**Figure 6.** Microstructure of fractured surface at portion 3

### 3.2 Microstructure of the non-fractured surface

Take the non-fractured piece of having frequency 16 Hz and do the grinding, paper polishing, rough polishing, fine polishing and drying the piece by using air pressure. Take the microstructure of the non-fractured surface in two directions, longitudinal and transverse directions by using optical microscope before and after etching.
Figure 7. Microstructure before etching in longitudinal direction.

Figure 8. Microstructure after etching in longitudinal direction.

Figure 9. Microstructure before etching in transverse direction.
3.3 Chemical composition of the sample

Chemical analysis of the two samples having frequencies 16 Hz and 18 Hz by using energy dispersive spectroscope (EDS) has been done.

| Sample frequency (Hz) | C    | Si   | Mn   | P    | S    | Cr   | Cu   | Nb   | V    |
|-----------------------|------|------|------|------|------|------|------|------|------|
| 16                    | 0.51 | 0.23 | 1.46 | 0.022| 0.019| 0.41 | 0.25 | 0.031| 0.047|
| 20                    | 0.51 | 0.23 | 1.47 | 0.021| 0.023| 0.41 | 0.26 | 0.029| 0.046|

Figure 10. Microstructure after etching in transverse direction.
3.4 Fatigue test results

Figure 11. Cycles vs crack length of 16 Hz sample.

As the no of cycles increases, crack length increases linearly which can be observed from the above figure 11.

Figure 12. Cycles vs crack length for 20 Hz sample.

Initial crack length is higher in case of 20 Hz sample as compared to the 16 Hz sample and also the crack length increases linearly with the increase in cycle as seen in the figure 12.

4. Conclusions

Considering rails, this technical review has outlined the materials used for them, the fatigue-induced damage to them, micro structural behaviour with the graph of crack growth rate, variations in crack length with load applied to them, and EDS analysis to them. It has also presented recent examples of R&D on railway system component ‘rails’.

Microstructure of the fractured surface shows the fatigue region. At portion 1 of the fractured surface pearlite regions dominate the fatigue region. At portion 2 of the fractured surface, more fatigue region is present and with increase of frequency it increases but for the frequency 22 Hz, pearlite
region again dominates. At portion 3 of the fractured surface, fatigue region dominates over pearlite region and it increases with frequency. Microstructure of the non-fractured surface before etching in longitudinal direction shows the sulphide inclusion which can be confirmed by the EDS analysis and chemical composition analysis. These inclusions should be avoided to improve the fatigue life of the material. Microstructure of the non-fractured surface before etching in transverse direction shows the pin-hole porosity which should be avoided to improve the fatigue life of the material.

5. References

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