RESIDUAL STRESS MEASUREMENT IN RAILS BY DESTRUCTIVE AND NON DESTRUCTIVE METHOD

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Abstract

Residual stress is an elastic stress in remaining part after the various stages of production. If residual stress values in rails are known, mechanical properties of rails and their effects in railway can be predicted. For this purpose, residual stresses of rails which had same casting number were measured by cutting and X-ray diffraction method in this study. Five rails were used for measurement. Firstly, according to the EN 13674-1 which is railway rails standard, strain gauge that is an electrical apparatus were used and one meter long rails were cut. After cutting, Hooke law was applied and residual stress values of rails were found. The residual stress values were around between 115 MPa and 180 MPa. In addition to standard residual stress measurement, X-ray diffraction method was used to compare between destructive and nondestructive techniques. Five specimens were taken from five rails in the appropriate size for X-ray device. In this method stress values were around between 200 and 400 MPa. After residual stress measurement, Brinell´s hardness test was applied to three samples and microstructure of rail which has biggest residual stress value was examined by SEM. The results show that, residual stress values in cutting method were different from X-ray diffraction method and residual stress could affect the rails hardness.

Keywords: Residual Stress, Cutting Method, XRD, Hardness, SEM

1. INTRODUCTION

Residual Stresses are a consequence of interactions among time, temperature, deformation and microstructure [1]. Residual stresses affect the performance and life of materials considerably. While Tensile residual stresses reduces the fatigue life of the material and may lead to premature damage, Compressive residual has the effect of increasing the fatigue life. Residual stress must be measured to understand this effect [2].

If the stress distribution is not uniform in the material which has plastic deformation, residual stress will also be produced [3]. Residual stresses can be formed inhomogeneous plastic deformations, thermal contractions, phase transformations during the production process and differences in the yield stress of the composite component [4].

Residual stress measurement methods must be developed. There are types of measurement methods. One is destructive and the other is non destructive method [5].

All methods of residual stress measurements were shown in **Fig. 1**. According to the railway rail standard, cutting method is acceptable residual stress measurement method [6]. A small pieces of materials are extracted from base material in cutting method. Then plastic deformation is calculated during and after cutting the material in order to stress relaxation. In addition to cutting method, X-ray diffraction that is a non destructive method was used to measure residual stress in this study. The distance between atomic planes in crystal structure can be increase or decrease thanks to applied stress and residual stress. If there is a residual stress in materials, this distance shows difference from non-stress regions. This difference is used then residual stress value is calculated [7]. The aim of this study was to measure residual stress and compare between this two methods.

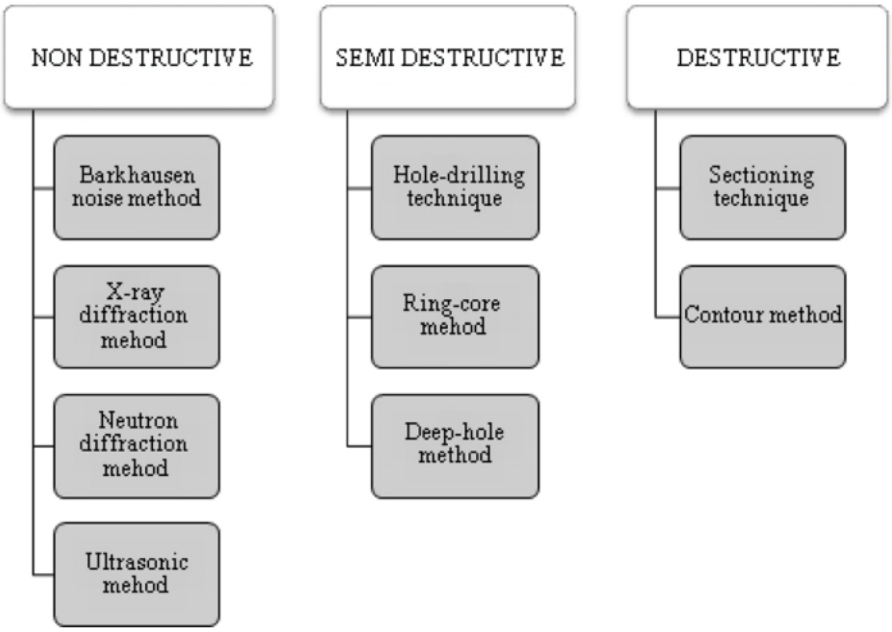


Fig. 1 Residual Stress Measurement Methods [5]

2. EXPERIMENTAL PROCEDURE

In this study, residual stress was measured by using cutting and X-ray diffraction method. The chemical composition of rails was shown in **Table 1**.

Table 1 Chemical composition of rails were used in study [6]

wt. %							ppm		Rm (MPa)
C	Si	Mn	P (max)	Cr (max)	Al (max)	V (max)	O	H	
0.60-0.82	0.13-0.60	0.65-1.25	0.030	0.15	0.004	0.030	20	2.5	880

After the residual stress measurement, brinell hardness of three samples were measured. The regions of hardness were shown in **Fig. 2**. Brinell hardness tests were performed under 187.5 kg load for 15 sec. accordance with the relevant standard. And finally, the rails were prepared as in standard metallographic procedure then their microstructures were analysed with Scanning Electron Microscope (SEM).

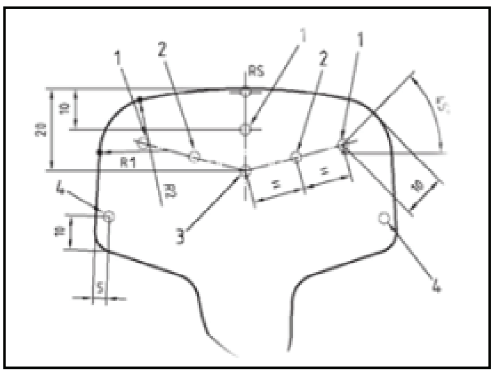


Fig. 2 Hardness regions of rails [6]

3. RESULTS AND DISCUSSION

Residual stress was measured of five rails, each of them has 1 meter long, by cutting method20 mm long slice was extracted from 1 m long rail according to this standard for residual stress measurement and strain gauge that is an electrical apparatus was used. During cutting, strain values of rails were obtained as a graphic. After cutting, hooke law was used then residual stress values were found. The residual stress values of specimens was given in **Table 2**.

Table 2 Residual stress values of rails by cutting method

Sample No	Strain (μm/m)	Residual Stress (MPa)
1	630	129
2	550	115
3	748	155
4	636	130
5	858	178

In cutting method, residual stress values were around between 115 MPa and 180 MPa. The highest residual stress was 178 MPa and the lowest is 115 MPa. In additon to cutting method, X ray diffraction method was used after taking specimens in appropriate size from RS (Rail surface) regions. The necessary parameters which were used in X-ray diffraction residual stress measurement was given in **Table 3**.

Table 3 Parameters were used in X-ray diffraction method

hkl surface	Lattice parameter (nm)			Young Modulus (Gpa)	Poisson Ratio	Wavelength (μm)	Brag Angle
	a	b	c				
222	2.86640	2.86640	2.86640	207	0.3	1.540562	137.18

Residual stress measurement values by X-ray diffraction method was given in **Table 4**.

Table 4 Residual stress values (X-ray diffraction method)

Sample No	Residual Stress (MPa)
1	129
2	115
3	155
4	130
5	178

These rail specimens which have same casting number showed different residual stress value. The main reason for this situation was different cooling rate of specimens. Therefore, residual stress was changed between 115 MPa and 178 MPa. These values were higher when X-ray diffraction method was used. The highest residual stress was 378 MPa and the lowest was 207 MPa in non-destructive method. Results of these two methods are compared in **Fig. 3**.

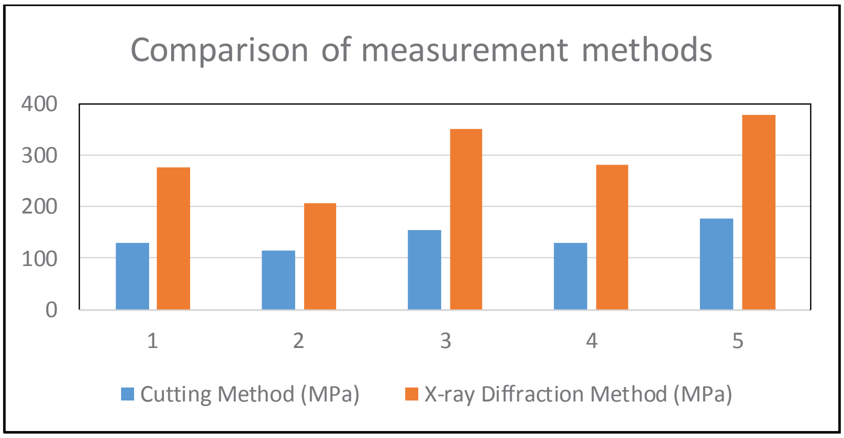
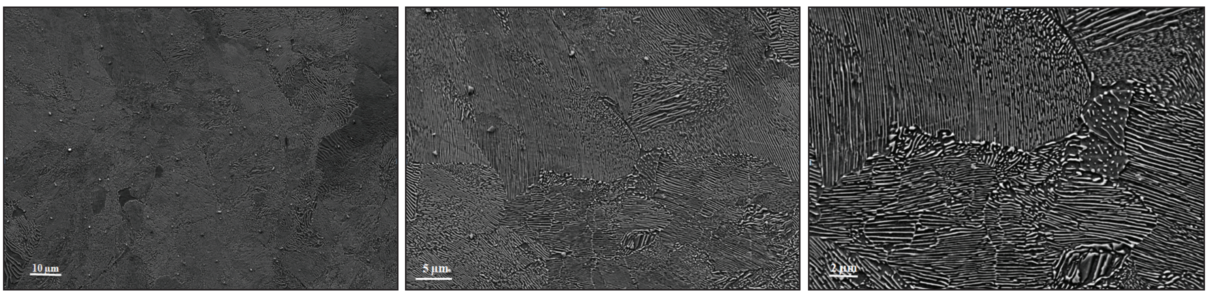


Fig. 3 Comparison between residual stress measurement methods of samples

There was a consistency between destructive and nondestructive method. After residual stress measurement with two methods, hardness distribution was performed to three of five samples. Their hardness values were given in **Table 5**.

Table 5 Hardness values of three samples

Measurement Regions	RAIL-1 (129 MPa residual stress)	RAIL-2 (115 MPa residual stress)	RAIL-5 (178 MPa residual stress)
RS	284	281	291
1-1	281	276	276
3	270	270	267
1-3	276	274	280
2-2	273	272	269
2-1	278	272	270
1-2	277	275	282
4-2	280	277	280
4-1	279	276	282



a) b) c)

Fig. 4 SEM images of rail a) 2000X, b) 5000X, c) 10000X

According to the EN 13674-1 Standard, these regions had been shown in **Fig. 2**. Residual stress changed with hardness. The main reason was to have different cooling rate of specimens for both residual stress and hardness. After hardness and residual stress measurement, microstructure analysis was performed of rail which has the biggest residual stress. SEM microstructures of this specimen were shown in **Fig. 4**.

4. CONCLUSION

Residual stress was measured both destructive and nondestructive method in rails. The residual stress values were different but there were a consistency between these two methods. For example, if the sample has biggest residual stress in cutting, at the same time ıt has biggest residual stress in X-ray diffraction method. In X-ray diffraction method, specimens have higher residual stress than in the other method. The reason for this situation, there is a regional residual stress analysis of materials. So that it isn't accepted method in rails. Residual stress changed with hardness because of the fact that both residual stress and hardness are mainly effected by cooling conditions.

ACKNOWLEDGEMENTS

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REFERENCES

[1] TOTTEN G., HOWES M., INOUE T. Handbook of Residual Stress and Deformation of Steel, ASM International, Materials Park, Ohio, 2002, pp. 3-4.

[2] TOTTEN G., HOWES M., INOUE T. Handbook of Residual Stress and Deformation of Steel, ASM International, Materials Park, Ohio, 2002, pp. 424-436.

[3] SCHAJER, G. S. Residual Stresses: Measurement by Destructive Testing, Encylopedia of Materials: Science and Technology, Elsevier, 2004, pp. 8152-8158.

[4] DRONAVALLI S.B. Residual Stress Measurements and Analysis by Destructive and Non-Destructive Techniques, University of Nevada, Las Vegas, 2004.

[5] YIGIT, O., DILMEC, M., HALKACI, S. Tabaka Kaldırma yöntemiyle kalıntı gerilmelerin ölçülmesi ve diğer yöntemlerle karşılaştırılmasi, 2008.

[6] EN 13674-1, 2011. Railway Aplications - Track - Rail - Part 1: Vignole Railway Rails 46 kg/m and Above, Brussels.

[7] PREVEY, PAUL S., X-ray Diffraction Residual Stress Techniques, Metals Handbook. 10. Metals Park, American Society for Metals, 1986, pp. 380-392.