Performance Comparison of Railway Wheel in terms of Fracture Mechanics and Flat Generation

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Abstract. For the high quality of wheel, the railway wheel has standardized such as UIC, KS, and JIS code but the chemical composition, the mechanical property and the hardness is merely requested. Although the standard of railway wheel has sustained, the damages of railway wheel have been occurred in service running. Because of wheel damage with spalling, shelling and thermal crack, the maintenance cost for the railway wheel has increased. In order to reduce wheel damage, it is necessary to reinforce the standard of railway wheel.

In present study, the fracture mechanics characteristics of railway wheel such as threshold stress intensive factor, fracture toughness and impact toughness and the flat generation have tested. The result shows that the standard of railway wheel has to supplement fracture toughness and impact energy depended on low temperature in order to reduce the wheel damage.

1. Introduction

The wheel/rail contact is characterized by high contact forces and small contact areas. Extreme and complex mechanical service loadings with static and dynamic stresses are superimposed by slipping and braking. The railway wheel has the standard such as UIC 812-3, prEN13262, JIS E5402 and so on. The chemical composition, tensile strength, hardness, impact energy and UT are included to the standards of railway wheel. Although the railway wheel materials are improved, the damages of railway wheel have been occurred in service running as shown Fig. 1.

Fig. 1 wheel damages

In general, the wheel tread is damaged by flat, shelling, and thermal crack and they occur under a variety of complicated conditions [1-3]. Hence, it is necessary to strengthen the standard of railway wheel in order to prevent wheel damages. Ghidini et. al.[4] have reported the comparison between North American and European steel grades in terms of standard mechanical properties. Karlsson et. al.[5] have developed the bainitic wheel superior to thermal fatigue resistance.

In the present study, the fracture mechanics characteristics of railway wheel such as fatigue crack growth, fracture toughness and impact energy depended on temperature have tested with respect to 3 wheel types. The flat generation test is carried out in order to compare the performance of railway wheels in-service running. The railway wheels have been examined with focus on the properties of railway wheel for performance comparison.

2. Experimental procedures

The characteristic tests of fracture mechanics were performed on full-size railway wheels used in service. Test samples were taken from several locations and in several directions from the wheel tread in KS R ISO1005. Fatigue crack growth rate and threshold stress intensive factor were carried out in accordance with ASTM E647. Fracture toughness test was carried out in accordance with ASTM E399. 1TCT or 1/2TCT specimens were used in the fatigue test and fracture toughness. The impact toughness tests were performed on a standard Charpy pendulum with impact energy of 300 J and an impact velocity of 5.6 m/s. The U notched specimens were tested in accordance with ASTM 23. Testing temperatures were in the range from –20 C to 20 ^{o}C. Table 1 shows the chemical composition of railway wheel used test.

Moreover, the flat generation tester as shown Fig. 1 is used to the flat test and the test is used to wheel and the rail which it uses in service as the material of the test piece. The rotation velocity is 1500 rpm during flat generation test and the brake time is 10 sec, and the contact pressure is 0.5 bar. The moisture and lubricant did not consider for this research.

Table 1 Chemical composition of tested wheel

	C	Mn	Si	P	S	Cu	Cr
Wh_A	0.606	0.72	0.37	0.006	-	0.02	-
Wh_B	0.668	0.66	0.33	0.015	0.002	-	-
Wh_C	0.520	0.72	-	0.012	0.008	0.10	0.25

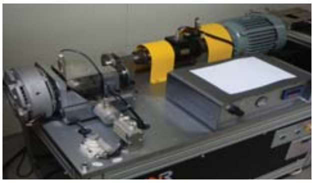


Fig. 2 Flat generation tester

3. Experimental results and discussion

3.1 Tensile strength and hardness

Fig. 3 shows tensile and yield strength in the tested railway wheel. As can be seen from Fig. 3, the highest tensile strength is in whA and whB, whereas the highest yield strength is in whC. The differences of tensile strength between the whA and whB specimens were not significantly. Tensile strength in tested specimen is satisfied to the standard of KS railway wheel but the wheel damage has continuously occurred. Therefore, it is necessary to evaluate other mechanical characteristics. Fig. 4 shows the result of hardness test in 70mm depth from wheel tread surface. The hardness values of 3 specimens are corresponded to the KS railway standard. The hardness decrease with depth of wheel tread and the reasons is probably due to the rim chilling and also to surface hardening during manufacturing and work hardening during operational loading. The whC is softer than whA and whB, while the deviation of hardness value in whB is demonstrated.

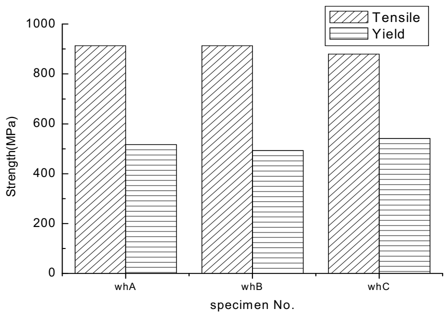


Fig. 3 Tensile and Yield strength

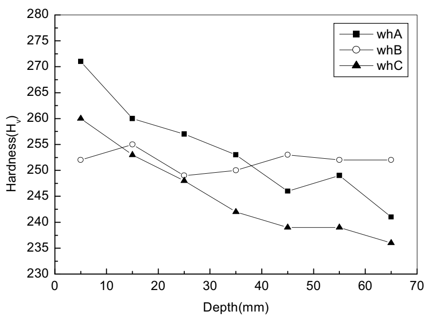


Fig. 4 Hardness

3.2 Impact and fracture toughness

It is a well-known fact that the yield strength (or hardness) cannot be the only measure to quantify that fatigue strength of high performance materials since increased brittles and material defects may reduce the fatigue strength. As can be seen from Fig. 5, the impact energy demonstrates relatively large discrepancies from the point of view of service temperature. The impact energy of wheel tread at room temperature has significantly higher impact toughness. The whC showed significantly higher impact energy than the whA and whB. In case of whC, the impact toughness is high at low temperature and room temperature. This means that the wheel tread of the whA and whB has the weakness with respect to brittle fracture, although in-service temperature for railway vehicle wheelsets is between –20 ^{o}C to + 20 ^{o}C.

Fig. 6 shows the slightly decreasing trend in fracture toughness values of whB than whA. These results are in good agreement with metallographic observations where fine grained microstructure was observed at the tread location [6]. It is assumed that this variation of microstructure is due to the heat treatment and water cooling after heating that is applied only to the wheel tread. The high fracture toughness in the wheel tread is also caused by the heat treatment of the wheel, because diffusion is limited in the wheel tread and thus a structure with a higher degree of over saturation is attained. This results in a structure with greater hardness that is resistant to wear, but not as resistant to fracture resistance. The modification of railway wheel material can be conducted to increase the fracture toughness. The differences of static fracture toughness between whA and whB were not significant. The whC shows material of higher fracture toughness, as shown in Fig. 6. The fracture toughness values were obtained by average of 3 specimens respectively. Despite the increase of the desired tightening characteristics and the reduction of range, fracture toughness requirements have been introduced, with target values corresponding to those usually K_{IC}> 80 MPa m$^{0.5}$. This fracture toughness value is included to UIC 812 and prEN13262. The request of so high values concerning fracture toughness is in order to guarantee a further improvement at railway working in terms of reliability and safety, avoiding every kind of railway wheel unexpected brittle fracture.

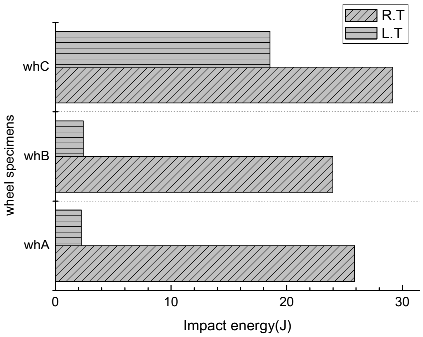


Fig. 5 Impact toughness

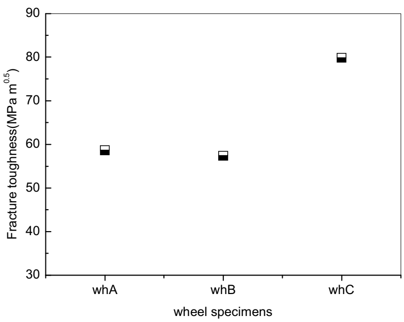


Fig. 6 Fracture toughness

3.3 Fatigue crack growth and threshold stress intensive factor

Fig. 7 and Fig. 8 show threshold SIF and fatigue crack growth rate. As can be seen from Fig. 7, the differences of wheel materials by threshold SIF are not shown, but the threshold SIF of circular direction is lower than that of the axial direction with respect to the direction of specimen. The threshold SIF of tested railway wheel is from 10 to 12 MPa m$^{0.5}$

Fatigue crack growth rate indicates crack propagation resistance after crack initiation in wheel. As can be seen from Fig. 8, the whC is slower than other wheel material. In case of the whC, the crack cannot be quickly propagated.

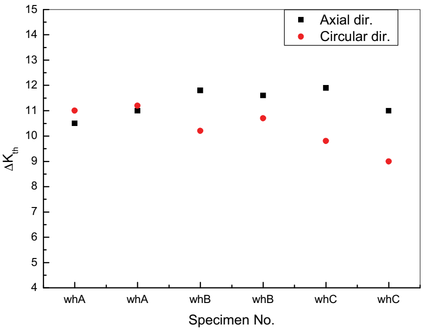


Fig. 7 Threshold SIF

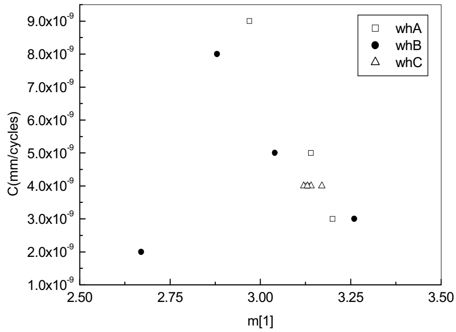
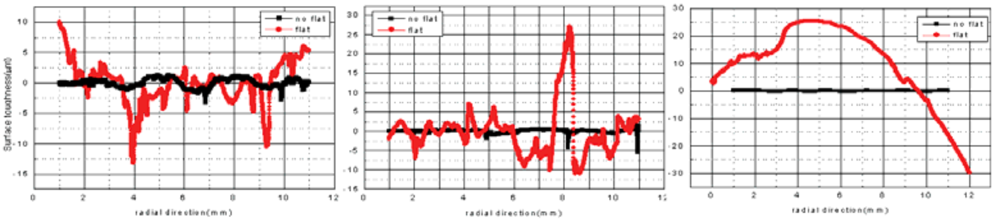


Fig. 8 Parameters of fatigue crack growth rate

3.4 Flat generation

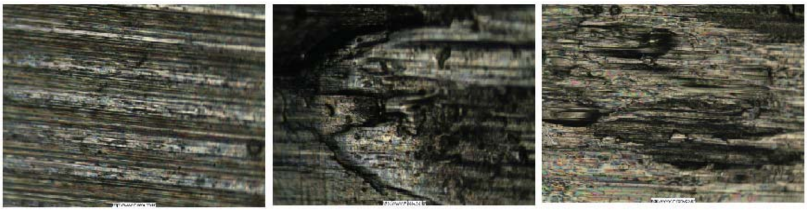
Figure 9 shows the graph comparing the surface toughness of the wheel tread of the flat generation test either before or after. In compares with whB, and whC, the surface toughness of the whA is relatively decreased. In the case of whC, the surface toughness is larger than the other specimen due to surface damage.



(a) whA (b) whB (c) whC

Fig. 9 Surface toughness

The type of flat generation for the wheel in service running is respectively different as shown in Figure 10. The flat of whA has been not occurred in compare to whB and whC under same test conditions and the trace in wheel initiated by rolling contact fatigue is merely demonstrated. In case of whB, the flat in wheel tread is generated and damage of concave type is occurred. Moreover, the flat is generated in case of whC.



(a) whA (b) whB (c) whC

Fig. 10 wheel tread after flat generation test

The flat generation test is performed with respect to 3 types wheel. It is different from type of flat generation and occurrence frequency in accordance with on wheel material. Therefore, it may be concluded that the damage of the railway wheel has been occurred depending on type of flat generation in wheel even if the mechanical property of the railway wheel is satisfied the requirement of the standard of wheel.

4. Conclusions

The fracture mechanics characteristics of railway wheel such as threshold SIF, fracture toughness, fatigue crack growth rate and impact energy and flat generation test are carried out for reinforcement of railway wheel standard. Gained results are summarized as follow.

(1) The standard of railway wheel has to add fracture toughness and impact energy depended on low temperature for reliability and safety of railway wheel.
(2) The threshold SIF and fatigue crack growth rate of tested wheel is not remarkably demonstrated but the crack initiation and propagation of wheel are different to axial and azimuthally direction.
(3) The damage of the railway wheel has been occurred depending on type of flat generation. The damages due to the flat has been differently occurred even if the mechanical property of the railway wheel is satisfied the requirement of the standard of wheel.

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