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Technical Review

Design Technologies for Railway Wheels and Future Prospects

Yoshinori OKAGATA*

Abstract

Solid wheels for railway need to have several characteristics such as enough strength, anti wear, anti thermal damage and noise / vibration characteristics. A solid wheel consists of three portions, that is, hub, web and rim. The characteristics for each portion are different each other. The web portion has to have enough mechanical strength against the loads caused by vehicle mass, and at the same time, its configuration is designed from the view point of thermal stress distribution. For the rim portion, steel grade is to be considered from the view points of anti wear and anti thermal characteristics each of which has different dependence on carbon content of the material. The material specification of wheels for domestic service was determined according to a series of research on wear characteristics of wheels and rails.

1. Introduction

A railway wheel, together with an axle, is one of the crucial parts that support the safe operation of railway vehicles. Wheels support the entire weight of cars; however, they cannot be designed as a fail-safe structure where a backup system by other parts can be applied in case of a serious problem. Therefore, absolutely high reliability is demanded in terms of strength. Accordingly, the most important and fundamental characteristic in designing wheels is strength.

However, since “being unbreakable” is a significant wheel characteristic, from the viewpoint of advantageous performance, characteristics other than strength, such as wear resistance, thermal crack resistance, and noise/vibration, are often focused. In particular, since wheels are expendable parts, their life plays a significant role in saving the maintenance cost.

In order to improve these characteristics, up to now, various studies have been conducted and technological developments have been made. There are mainly two approaches to improve the wheel performance: material designing and configuration designing. This paper shows the outlines of the various characteristics required for wheels, and introduces the results of research and development of the particularly important characteristics. Finally, after summing up the current issues to be discussed, the future prospect is considered.

Tired wheels are ones that consist of a tire and wheel center; however, in this paper, only solid wheels are discussed because they are most widely used at present.

2. Structure of Wheels and Required Characteristics

2.1 Structure of wheels and terms of parts

A solid wheel of a railway vehicle (hereinafter “wheel”) consists of three parts, as shown in **Fig. 1**. They include a hub, wherein an axle is inserted, a rim that contacts the rail, and a web that unites the two parts. The outer circumferential surface of the rim, which contacts the rail, is tread, and the projected part is flange.

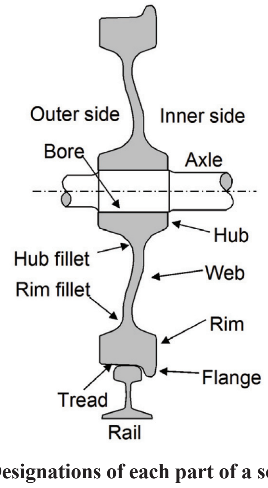

Fig. 1 Designations of each part of a solid wheel

* Dr.Eng., Osaka Steel Works, Railway, Automotive & Machinery Parts Unit
1-109, Shimaya 5-chome, Konohana-ku, Osaka City, Osaka Pref. 554-0024

2.2 Characteristics required for wheels

Following are the characteristics required for wheels:

(1) Weight: Wheels are unsprang parts; therefore lightweight is preferable from the viewpoints of their influence over riding comfort and bogie parts. This characteristic is especially important when designing high-speed vehicles.
(2) Web fatigue strength: A web must have sufficient fatigue strength to withstand cyclic mechanical stress caused by the weight of the car body.
(3) Rolling contact fatigue strength of tread: Sufficient fatigue strength to withstand the rolling contact stress (Hertz stress) between the tread and rail is necessary.[1)]
(4) Characteristics of stress alternation caused by thermal attach: When a rim expands because of thermal input caused by tread braking, thermal stress is developed at the web and rim areas. Sometimes the excessive thermal input changes the normal stress distribution given by the production stage into an abnormal situation.
(5) Thermal crack and fracture resistance: This is the characteristic relating to thermal cracks initiated on a rim by the frictional heat generated by tread brake and their propagation. In worst case, wheel fracture takes place.
(6) Wear resistance: Abrasion/wear is developed on a tread when it is in contact with a rail. In case of a tread brake wheel, it is also developed by the friction between brake shoes and the tread. This is the characteristic directly related to wheel life. In some cases, nonuniform wear becomes problematic rather than the wear amount itself.
(7) Running performance: Running stability on a straight track and curving performance are to be evaluated basically from the viewpoint of the whole performance of a bogie. However, the tread profile is one of those factors.
(8) Acoustic characteristics: Reduction of wheel running noise is required from the viewpoint of environmental demand. There are several approaches such as improvement of bogie structure or oil lubrication on rails. As for the countermeasures taken for wheels, noise dumping wheels fitted with sound absorbers are generally employed.
(9) Vibration: Vibration caused by a wheel is basically classified as the one caused by damages on a tread and the other caused by imbalance of a wheel. The former is influenced by the abovementioned rolling contact fatigue strength and the wear resistance of the tread. The latter, balance characteristic, generally depends on the machining accuracies at manufacture and/or maintenance. This characteristic is important for wheels of high-speed vehicles in particular.
(10) Axle gripping force: This is a characteristic to fix a wheel onto an axle firmly. However, there is no problem in general when interference and press-fitting force are properly controlled as per regulations.

3. Designing of Web

Among the characteristics listed above, particularly important designing technologies are described in detail hereunder. However, as for the hub, as already mentioned, there is almost no variation in designing. Therefore, description will be focused on major characteristics of the web and rim.

In the first place, following characteristics with respect to the web are addressed to in the order listed.

(1) Designing of web configuration under the mechanical loads
(2) Fatigue strength of web material
(3) Relationship between web configuration and thermal stress distribution caused by braking

3.1 Designing of web configuration under the mechanical loads

3.1.1 Kinds of mechanical loads

There are two kinds of mechanical load exerted onto a wheel: vertical load and horizontal load. As shown in **Fig. 2**, vertical load is one produced by supporting the car weight in the vertical direction. Regarding the horizontal load, there are two kinds: lateral load and back load. The lateral load is acting onto the flange fillet of the outer wheel from the outer side of the curved track to the inner side. The back load is acting in the opposite direction of the lateral load onto the back surface of the inner wheel's flange. Since the lateral load is continuously produced when passing the curved track, it is the most critical load in designing the strength of the web. On the other hand, the back load is only produced by the contact between the backside of a wheel and a guard rail, mainly when passing a switch. This means that the back load takes place far less frequently than the lateral load. Therefore, in some standards, the back load is not considered in designing the strength of the web.

3.1.2 Types of web configuration

The web configuration of the wheels for domestic services is classified into three types—Type A, Type B, and Type C—as shown in **Fig. 3**. Type A wheel has a concaved web as shown in a); on the other hand, Type B wheel has a convex web, as shown in b). Type C wheel has a straight web that is perpendicular to the axle, as shown in c).[2)]

As mentioned above, a wheel is subjected to the vertical load P and lateral load Q whenever a car passes on a curved track. Accordingly, as shown in **Fig. 4**, the composite force of the two forces acts in an upward direction at the contact point with the rail, inclining toward the inside of the wheel set. The maximum stress in the web is generated at the hub fillet. However, as shown in the figures, since the the arm length of Type A (La in the figure) is shorter than that of Type B (Lb), the bending moment of Type A is less than that of Type B even when the loading conditions are the same. In other words, the web configuration of Type A is superior with respect to strength. Therefore, Type A configuration is most widely employed, regardless of whether domestically or overseas, unless restricted otherwise.

Configuration of Type B is designed for creating a space inside of a driven wheel set for installation of a driving gear unit in narrow gage service. Since this web design is inferior to Type A web with

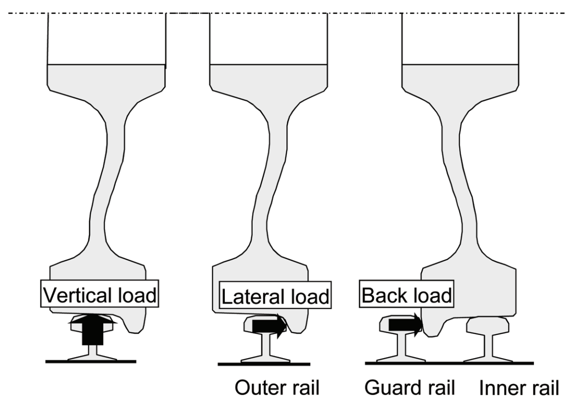

Fig. 2 Positions and directions of the mechanical loads

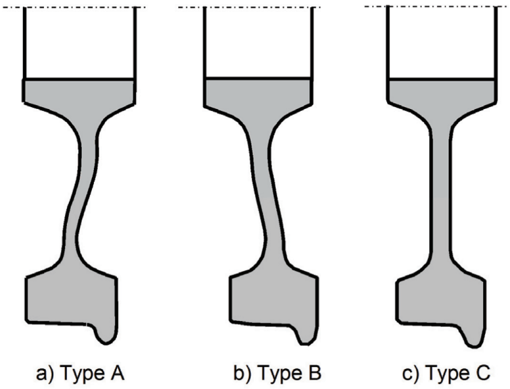

Fig. 3 Typical web configurations

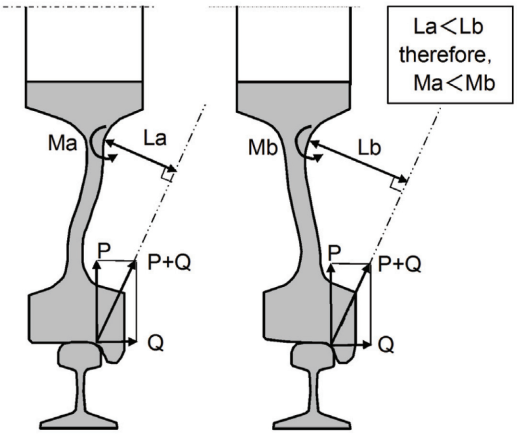

Fig. 4 Comparison of bending moments

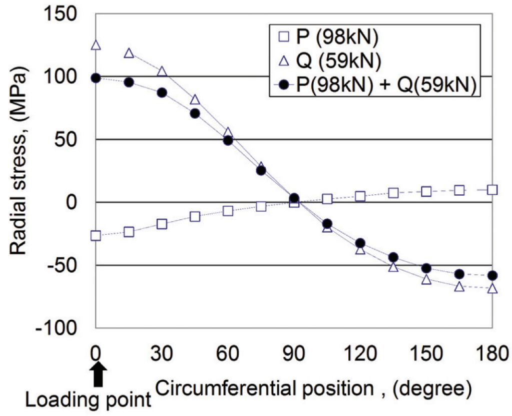

Fig. 5 Stress cycle by mechanical loads

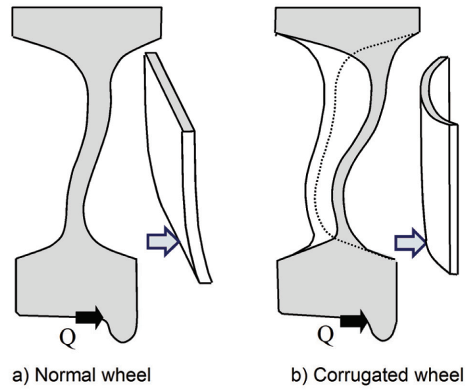

Fig. 6 Concept of web design of the corrugated wheel

respect to strength, the web thickness of Type B must be more than that of Type A.

Configuration of Type C is designed generally for a wheel equipped with disc brakes on both sides of the web. It has a flat shape usually.

However, these designations of Type A, Type B, and Type C are only used in Japan, and not accepted globally. As long as the author knows, there is no specific term in English that is commonly used worldwide. Sometimes, Type B wheel is called "Reversed web wheel" and Type A wheel is called "Normal web wheel."

3.1.3 Stress cycle

Stress in the web area is estimated on the basis of the static axle load (the maximum load on a wheel set when the vehicle is stopping) and the additional loads caused by dynamic vibration, passing a curved track, and so on. However, the additional factors differ depending on the standard of the respective country (region).

In Japan, "JRIS J 0405: Rolling Stock - Verification of the fatigue strength of the solid wheel web (JRIS: Japan Association of Rolling Stock Industries Standard)" is specified for wheels for local line service.[3] According to this standard, an example of stress cycle that is evaluated on a typical Type A solid wheel for domestic local service is shown in **Fig. 5**. Since this standard does not specify the back load, the figure shows three kinds of stress caused by vertical load P, lateral load Q, and a combination of these two loads. Stress measurements are made on each side of the web, and the figure shows the stress at the outer hub fillet, where the maximum stress takes place. Since this figure shows half of a complete cycle, matching with another half cycle produces complete one cycle. According to this figure, it is clear that the influence of lateral load is relatively large. Furthermore, in the case of Type A wheel, stress due to vertical load and that due to lateral load have opposite signs; therefore, the absolute value of the total stress becomes smaller than the sole value caused by lateral load alone.

Although thicker web naturally reduces stress, web stress varies depending on the web offset, too (Refer to clause 3.3.1). Therefore, optimum configuration is always studied considering the thermal stress characteristic, which is described later.

3.1.4 Corrugated wheel

Corrugated wheel is one of the notable wheels when discussing the web design.[4] As **Fig. 6** shows, since the circumferentially corrugated web improves rigidity against lateral load, web thickness can be reduced, which means less weight of a wheel. The web thickness of the corrugated wheel is approximately 30% less than that of a usual web wheel.

3.2 Fatigue strength of web

As mentioned above, cyclic mechanical stress is exerted on the web; therefore, the web material must have sufficient fatigue strength to withstand the stress cycle.

As for the web fatigue strength of wheels for domestic service, the Railway Technical Research Institute, JNR, reported the result of a fatigue test conducted in 1958.[5] According to the results, the allowable stress 157 MPa (16 kgf/mm^2) has been applied to the web

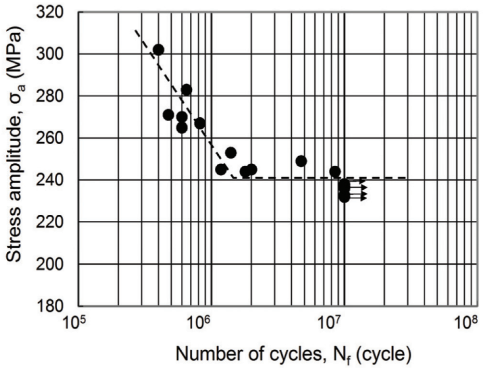

Fig. 7 Fatigue test results of the domestic wheels

design. In 1972, Hirakawa et al. reported fatigue test results using full size wheels.[6] However, since then, no systematic fatigue tests have been conducted. Therefore, the author conducted investigations from 2004 to 2006. **Figure 7** shows the results of the study on typical wheels for domestic local services. As shown in the figure, the fatigue strength was found to be approximately 240 MPa.

In the abovementioned JRIS J 0450, a standard for designing domestic wheels, it is specified that the allowable design stress is 160 MPa. This value was determined on the basis of the value of 157 MPa, which has been applied for many years. Because the actually measured value of 240 MPa is 1.5 times of this value, in other words, it can be said that the above allowable designing stress has a safety factor of 1.5.

Note that the results in this figure were obtained under a web surface condition of shot peening without machining. Studies on the effect of the machining condition on the fatigue strength were also conducted. Although, the details of the study are not mentioned in this paper, the results show that the residual stress of the machined surface influences the fatigue strength considerably.

3.3 Relationship between web configuration and thermal stress distribution caused by braking

3.3.1 Reversal change of the residual stress due to thermal input by braking

When braking is applied via brake shoes pressed onto a wheel tread, temperature of the tread increases because of friction. Normal braking for the usual stop operation has almost no influence on the performance of the wheel. However, drag braking when running a long downhill or a stuck brake shoe due to malfunction of a braking system heats the whole rim section to a high temperature. Because of the thermal expansion of the rim, the rim pulls the web outward, and then tensile radial stress is generated in the web area.

When this thermal radial stress exceeds the yield stress of the web material, outward plastic deformation of the web takes place. After the brake shoe is released and the wheel is cooled, the rim tends to shrink; however, the expanded web disturbs the rim to shrink. As a result, the web pushes the rim outwardly, and then causes the tensile stress in the rim. When manufacturing the wheels, compressive residual stress is originally given by heat treatment. However, in the case as mentioned above, this initial residual stress changes from the compression side to the tension side. This is the "reversal change in the rim residual stress." Once this happens, small thermal cracks on the tread surface start to propagate and result in a brittle fracture of a wheel in the worst case. Accordingly, stress in this situation is very dangerous. **Figure 8** shows the above process graphically.

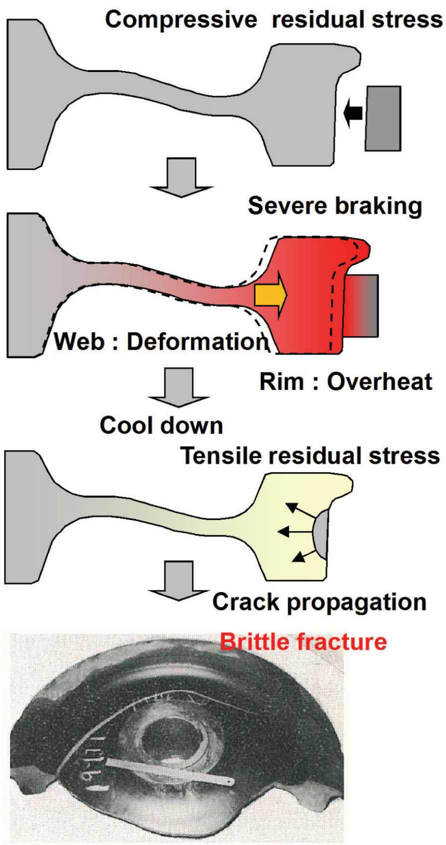

Fig. 8 Initiation of the tensile residual stress in the rim

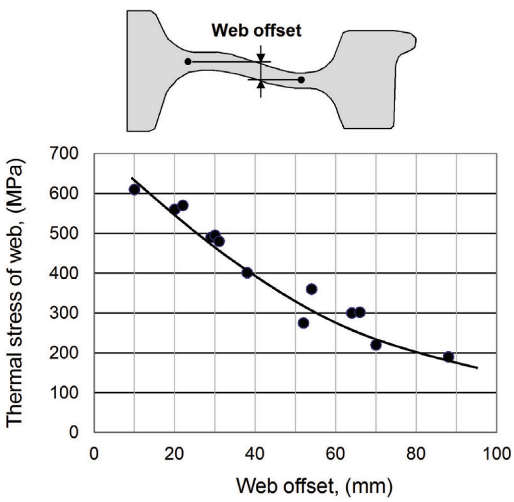

Fig. 9 Thermal stress of web depending on web offset

However, according to studies conducted in 1970s, it was found that this change in residual stress can be controlled by improving the web configuration.[7] The key parameter is the web offset, as shown in the upper part of **Fig. 9**. As clear from the graph in the figure, when the web offset is increased, thermal stress of the web is decreased. This means that the web offset can reduce the plastic deformation of the web because of yielding. Therefore, the shrinking of

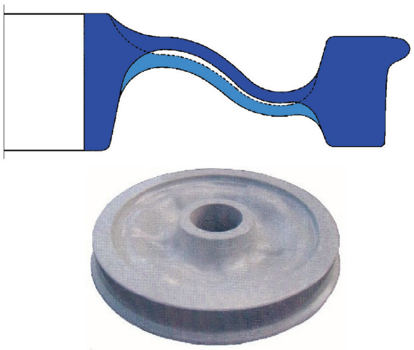

Fig. 10 High toughness corrugated wheel

the rim is not disturbed by the web when cooling, and consequently, the reversal change in the residual stress in the rim does not occur. A wheel developed on the basis of this concept was named High Toughness (HT) wheel by the then Sumitomo Metal Industries, Ltd.

In 1970s, several hundred cases of fracture of freight car wheel due to severe braking were reported in U.S.A., and HT wheels were developed as a countermeasure against this trouble.

Application of HT wheels drastically reduced the number of fracture, and later, for U.S. freight cars, it became mandatory to use wheels having web configuration like HT wheels.

Service condition of domestic wheels is not so difficult as compared with the freight car wheels in U.S.A. However, in order to give the wheels higher safety, a new wheel has been developed on the basis of the same concept of HT configuration. It is a new Type A corrugated wheel that has improved thermal resistance, as shown in **Fig. 10**.

4. Designing of Rim

Next, the following characteristics of the rim are described:

(1) Wear characteristic of tread
(2) Thermal crack and fracture resistance of rim
(3) Rolling contact fatigue strength of tread

4.1 Wear characteristic of tread

4.1.1 History of wheel materials in Japan

Wear characteristic of tread directly influences the life of a wheel; therefore, it is a very important characteristic from the viewpoint of economy, namely maintenance cost. The major factor that influences the wear characteristic is the carbon content. The higher the carbon content, the higher the wear resistance. However, higher carbon content tends to increase thermal damage; therefore, overseas standards of wheel materials generally specify several steel grades from lower to higher carbon content. **Table 1** shows carbon content and hardness of respective steel grade of AAR Standard of U.S.A. and EN Standard of Europe. On the other hand, Japanese standard for wheel material specifies only one steel grade with carbon content of 0.60% and more, as shown in the table. There is a historical background as mentioned below.

Around 90 years ago, there was a significant problem of short life of railway wheels[*1] because of excessive wear in Japan. Because the railway technologies of Japan have been imported from Europe, wheel material at that time was low carbon steel (carbon content of around 0.5%), which was generally used in Europe at that time. It was estimated that increase in carbon content would be effective to give the wheel a longer life; however, it might shorten the rail life. Then, a joint project by government and a civilian sector was organized to find the optimum combination of the wheel and rail materials. Dr. Saito et al. built a circular track having a diameter of 24.4 m in the premise of the then Sumitomo Metal Industries, and ran a miniature car equipped with wheels of approximately one third in scale. They measured the amounts of wear of rails and wheels for various combinations of materials.

After around seven years of investigation, they reached an unexpected conclusion. That is, increase in the carbon content of a wheel reduces not only the wheel wear but also the rail wear. **Figure 11** shows the results of wear amount of each combination. For each combination, the wheel material was selected among three levels of carbon contents, and the rail material was selected among the three levels. The reason why this conclusion was obtained can be explained as follows. Since the fine particles that were removed from the wheel and/or rail surface works as abrasive material between the tread and rail, they promote the wear both of wheel and rail. This means that the lesser wear of a wheel reduces the amount of abra-

Table 1 Steel grades specified by EN, AAR and JIS

Region	Specification	Steel grade		Carbon content (%)	Hardness HB
Europe	EN 13262	ER6		≦ 0.48	234-270 *
		ER7		≦ 0.52	247-282 *
		ER8		≦ 0.56	258-296 *
		ER9		≦ 0.60	300-350 *
North America	AAR M-107/ M-208	Class L		≦ 0.47	197-277
		Class A		0.47-0.57	255-321
		Class B		0.57-0.67	302-341
		Class C		0.67-0.77	321-363
		Class D			341-415
Japan	JIS E 5402-1	SSW	QS	0.60-0.75	246-307
			QR		311-363
			QRH		295-347

* Equivalent hardness according to specified tensile strength

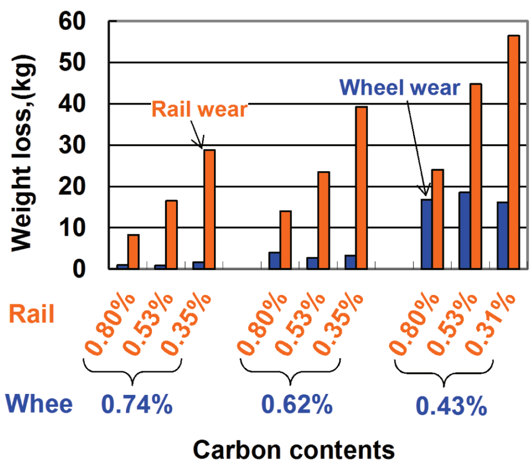

Fig. 11 Abrasion tests by miniature vehicle

[*1] Wheels at that time were not of solid type, but of built-up type, wherein a tire was shrink-fitted to the wheel center. However, the material for the tire was also applied to the wheel later; therefore, they are treated as an identical type in this paper.

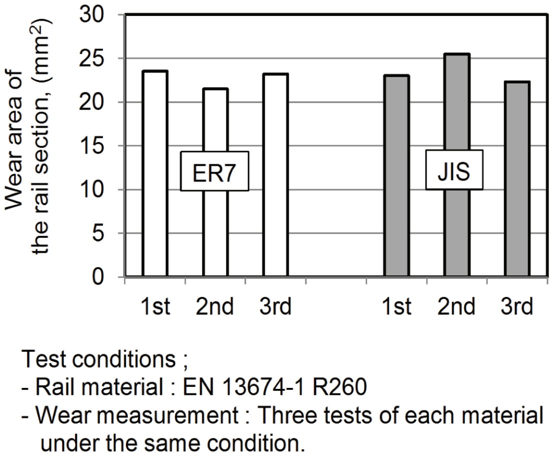

Fig. 12 Rail wear depending on wheel materials

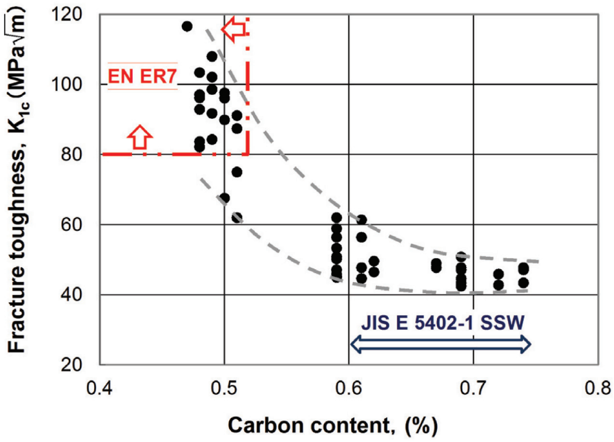

Fig. 13 Fracture toughness depending on carbon content

sive material, thereby reducing the wear of a rail. Then, it was concluded that even if the carbon content of a wheel is increased, the rail life would never be shortened, but rather may become longer.

In general, a test piece for the wear test has a cylindrical figure with a diameter of several tens of millimeters, which is rotated under some contact pressure with a certain slippage between the wheel specimen and rail specimen. In this method, since the particle removed from the test specimen scatters, no influence by this dropped particle is observed. This is why the conclusion of the above test was quite different from other past test results.

Later, on the basis of this result of investigation, the specified value of the carbon content of the wheel material has been gradually increased and has finally reached the present level of JIS Standard (0.60%– 0.75%).

4.1.2 Comparative investigation of EN and JIS wheel materials and of their influence on rail wear by Deutsche Bahn

Deutsche Bahn (DB) had been suffering from the un-roundness problem of wheels for high-speed trains ICE 1 and 2. Since there was no such trouble of wheels for Shinkan-sen in Japan, DB conducted comparative running tests on actual trains. The lives of the wheels made of JIS material for Shinkan-sen were applied to ICE 1 and 2 wheels compared with those of wheels made of ER7 material of EN Standard (carbon content: 0.52% or less) which was applied to conventional ICE wheels. After six years running test since 2003, the JIS material wheel demonstrated remarkably better wear resistance, which gives 1.5 times longer life than the ER7 material wheels.

In parallel with the running test on actual trains, investigation on wear of rails was also conducted using full size wheel-rail testing rig. In this test, a full size wheel was loaded on the full size straight rail which repeats the lateral oscillation. Therefore, it is considered that the abovementioned fine particles remain on the rail surface and work as abrasive material. **Figure 12** shows the result of comparative tests using two kinds of wheel material, ER7 and JIS, and the results show that the rail wear amounts are almost equal. This result does not show less amount of rail wear by wheel material having higher carbon content. It differs from the conclusion of the result by Dr. Saito et al.; however, it can at least be concluded that higher carbon content of wheel material does not have any harmful influence on rail wear.[8)]

4.2 Thermal crack resistance and fracture toughness of the rim

In case of a wheel with tread brake, even under normal braking condition, initiation of very fine thermal cracks at the tread surface layer cannot be avoided because of cyclic heating and cooling. Generally, the higher the hardenability of a material, the more thermal cracks are initiated; therefore, lower carbon content is preferable from the viewpoint of preventing thermal cracks.

Furthermore, as described in section 3.3, application of severe brake onto tread causes tensile residual stress in the rim, and subsequent cyclic braking makes such fine cracks to propagate, in certain cases leading to a brittle fracture. In fact, a bigger crack and larger tensile residual stress cause the brittle fracture more easily. However, even under the same condition, fracture resistance varies depending on materials. This resistance against brittle fracture is represented by an indicator termed as fracture toughness, based on fracture mechanics. In general, lower carbon material has higher fracture toughness, that is, it has greater resistance against brittle fracture. **Figure 13** shows the relationship between the fracture toughness of the rim and carbon content.

As mentioned above, low carbon material has better thermal crack resistance and fracture toughness, but has less resistance against wear, as introduced in clause 4.1. Accordingly, in selecting wheel material, an appropriate level of carbon content is to be selected on the basis of the braking condition in service and the actual situation of maintenance.

According to the new European Standard for wheels (EN13262) established in 2004, the minimum value of fracture toughness is specified for tread brake type wheels.[9)] This is a unique provision among the standards for wheels in the world. In Fig. 13, the acceptable area for ER7 is shown. When this standard is applied, the material with carbon content more than 0.50% cannot be used for wheels with tread brake. On the other hand, in Japan, many wheels made of the material with carbon content more than 0.60% are applied to the tread brake system without any problem. This owes much to sufficient maintenance work of the brake system to prevent abnormal braking condition, which may result in reversal change in the residual stress in the rim. It may be said that this concept is based on a different way of thinking between Europe and Japan.

4.3 Rolling contact fatigue strength of tread

In recent years, in Northern America, tread damage at the contact surface between tread and rail has become a serious problem for the wheels of heavily loaded freight cars such as double container cars. In these cases, the wheel loads are almost double of those for

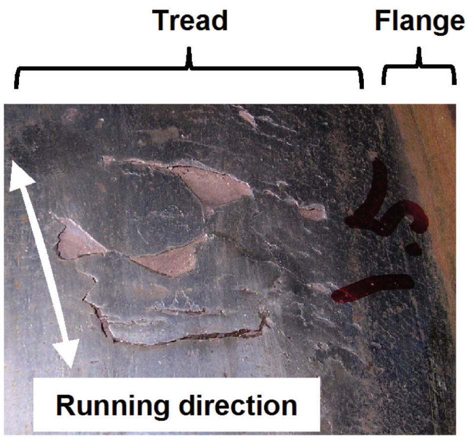

Fig. 14 Example of shelling of AAR freight wheel

usual passenger cars. **Figure 14** shows an example of such damages. It is generally termed as shelling. At the first stage, a crack is initiated because of the heavy rolling contact stress in the layer just under the tread. Subsequently, it propagates to the surface of the tread and sometimes causes fracture of the rim.

In order to solve this kind of problem, AAR revised the specification for the wheel material in 2008. They added a new steel grade of Class D, which has higher hardness than Class C. However, its carbon content is same as that of Class C, which belongs to high carbon steel.[10] At present, wheel manufacturers are developing a process to satisfy these new requirements. Addition of alloy elements and/or rapid cooling at the heat treatment stage are effective; however, cautions must be paid not to cause martensite and/or bainite structure, because such structures may have less resistance against wear and/or thermal crack as compared to the pearlite structure.

5. Conclusion

It was about sixty years ago when solid wheels were put into practical service in Japan. Since then, the steel quality of the wheel material has been drastically improved owing to the development of continuous casting. At the same time, design procedure of wheel configuration has been also innovated by design tools, such as computer analysis. However, almost all materials for wheels are still plain carbon steels. Moreover, the basic structure of the wheel has been unchanged, which consists of the hub, web, and rim. The reason why both material and configuration have been stable for such long years can be based on the concept of "simple is the best." This concept has arisen from the fact that the wheel plays one of the most important parts in supporting the safety operation of the railway. Before the development of the solid wheel, it was assembled with a tire and a wheel center. However, the reliability of the wheel was significantly enhanced after the development of hot rolling technologies for manufacturing the solid wheel. Therefore, there will be no drastic change in the wheel structure in the future.

However, in recent years, the following technical trend of the wheel has become clearer: a specific characteristic of the wheel is required depending on the category of the service. It can be said that Europe, U.S.A., and Japan have been leading the wheel technologies in the world. However, in Europe and Japan, their technologies are mainly focused on passenger cars including high-speed vehicles. On the other hand, in U.S.A., the share of wheels for freight cars is significantly high; therefore, majority of the technical development relates to this area. Needless to say, characteristics required for the passenger car and the freight car are not the same. In summary, reliability is of first priority for passenger car wheels; therefore, somewhat higher cost may be acceptable. On the other hand, for freight car wheels, the greatest interest concerns initial and maintenance cost.

This difference in the way of thinking appears in the standards of U.S.A. and Europe. Since the beginning of this century, EN Standards in Europe for wheels and axles have been established one after another. They are prepared to be commonly applied to all EU countries. Their base standards are UIC Standards (International Union of Rails);[11] however, several new provisions were added when converting them into EN Standards. For a typical example, a new classification of Categories 1 and 2 was specified for wheels for high speed and conventional speed, respectively. Why such addition and/or ramification of provisions were/was made? The first reason must be to procure wheels having higher quality. The second reason seems to be that the specification for procurement is requested to be more detailed and strict in order to prevent the incoming of inferior quality products delivered by newly entering manufacturers because EN specification has a function to open the European market to any supplier. From the other viewpoint, since many experts joined the investigation and discussion to establish the specification, it is a great opportunity to deepen the technologies for the wheels.

On the other hand, US standards for freight cars are basically quite simple. Only chemical compositions and hardness are specified for material quality. The concept of AAR, in general, may be based on American way of thinking, that is, "Not so essential cost is to be minimized and a better technology is to be applied as soon as possible." Accordingly, they are always positive toward the new proposal of manufacturers. Therefore, it is important for suppliers to make efforts in knowing market needs and to promote the development of corresponding technologies as quickly as possible.

In the field of railway standards, there has been a big move recently. It is organizing of TC269 (Technical Committee 269) for Railway Applications in ISO (the International Organization for Standard). The first general meeting of TC269 was held in October 2012 in Germany. The committee has started the work to discuss a new ISO standard for railway applications. In Japan, the Railway International Standards Center was organized in the Railway Technical Research Institute in April 2010. It will promote the discussion to propose the draft of international specifications and participation in international conferences. As far as the specifications for wheels and axles, no international meeting is scheduled at present. However, preparations must to be made for the international meeting that may be held in the near future. In the history of establishments of ISO standards, European countries have been usually taking initiative. This means that EN Standard may also be converted into ISO Standard in the future. Therefore, continuous attention must be paid to the movement of EN Standards and to make efforts to accumulate our technologies, which will be effective in supporting our proposals when discussing the revision of ISO standards.

In this paper, design technologies for railway wheels have been introduced. However, these technologies are only minimum conditions to secure the wheel reliability. Moreover, the most important issue is incorporating high quality into the wheels during their manufacturing stage. In other words, continuous improvements in the manufacturing procedure and daily management of technologies and workmanship are necessary to guarantee sophisticated and homogeneous quality of the wheels. This is a mission of ours, and this concept can be a source of high competitive performance in the global market.

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Yoshinori OKAGATA
Dr.Eng.
Osaka Steel Works
Railway, Automotive & Machinery Parts Unit
1-109, Shimaya 5-chome, Konohana-ku, Osaka City,
Osaka Pref. 554-0024