Recent Trends in Research and Development into Materials Technology for Railways

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Innovation in railway technology can be achieved through progress in material technology, in terms of the development of the materials themselves, manufacturing processes, higher reliability, etc. Developing material technology is therefore essential for railways. To this end, analytical and mensuration methods are regarded as other basic technology. Today it is also necessary to meet environmental demands, by replacing harmful materials with environmentally acceptable substances, and ensuring that they are energy efficient. This paper describes some of the latest results from research and development into material technology, including the development and application of new materials, and analytical and mensuration methods.

Keywords: materials for railway, new materials, performance improvement, functional improvement, analytical technology, mensuration technology

1. Introduction

It can be said that the advancement of material technology has brought about the development of railway technology. For instance, elemental technologies, such as the improvements of adhesion performance, brake performance, current collection characteristics and other performance including members’ performance, in addition to weight reduction, contribute to the improvement of vehicle velocities. One of the factors of any of them is that many technologies have been incorporated in development of materials, advancement of processing technology, and ensuring reliability. Therefore, research and development of materials for railway need to be addressed as a key to support the future development of railway. On the other hand, since railway transportation is subject to ensuring safety, it is necessary to properly meet the needs of railway operators, including the longer service lives and functional improvement of the members currently in use, the deterioration judgment for structures, etc. supplied for use and reduction of maintenance work. In the course of progress, it is vital to elucidate such phenomena as physical and chemical changes which become obvious in a form of degradation, and improvements in analytical and mensuration technologies are essential for that purpose. In recent years, addressing global environment issues is becoming one of the major tasks in addition to the above listed, including the demands for reduction of energy consumption and replacement of environmentally unacceptable materials with alternative, acceptable ones.

This article introduces tasks concerning vehicles and facilities mainly including research on the development of new materials and the study of their application to railways, and the outline and results of RTRI work on material analyses and various mensuration technologies, which can help provide insight into phenomena leading to deterioration, and in the conclusion, discusses prospects for the future.

2. Research and development on materials for railways

Table 1 summarizes a series of examples of RTRI work dedicated to technological development of new materials. Although in most cases work relates to the development of new materials, areas of research can be categorized into the development of materials themselves and research into application of these materials for railways.

2.1 Improvement of the basic characteristics of high-temperature superconducting materials, and the development of feeder cables

Research in this field has focused on the synthesis and evaluation of these materials, and processing them into bulk materials and wire rods. So far positive results have been achieved in terms of performance and functionality. For instance, the trapped magnetic field values were improved by adding a zinc element as an impurity to yttrium-based bulk materials, and in another case, bulk materials were reinforced through resin impregnation to improve the mechanical strength and prevent degradation due to water. Technical developments are being investigated as well, to improve productivity and reduce costs [1]. Other research and development is seeking to use superconducting cables as railway feeder cable. Evaluation of these cables is being carried out in various ways, for example, by installing them along the test lines in RTRI facilities and conducting vehicle running tests [2].

2.2 Development of flame-resistant magnesium alloy for car bodies

One method for saving energy is to reduce the weight of car bodies. Trials have been conducted to achieve this by employing aluminum alloys to build car bodies [3]. Given that magnesium is relatively lighter than other common metals, RTRI has been conducting studies into the application of flame-resistant magnesium obtained by adding
Table 1 Examples of RTRI’s recent developments and application of new materials, and analytical and mensuration technologies

| Category | Field | Parts | Applicable material/technology | Main effect(s) expected |
|----------|-------|-------|--------------------------------|------------------------|
| New materials | Electric power | Cables | Superconducting materials | High temperature superconducting performance |
| Rolling stock | Car bodies | Flame-resistant magnesium alloy | Light weight, noncombustibility |
| Lubrication grease | Nanocarbon | Electrical conductivity, mechanical characteristics |
| Pantograph contact strips | C/C composite | Fracture toughness |
| Facilities | Sleepers | Geopolymer concrete | Environmental load reduction during manufacturing process, and resistance to alkali-silica-reaction, degradation, fire, etc. |
| Concrete | Ion-exchange materials | Alkali-silica-reaction suppression |
| Sheets for embankment slope protection | Halogen-free materials | Environmental acceptability |
| Movable nose crossings | Steel rail head heat treatment method | Anti-wear performance |
| Crack detection system for rails, etc. | Conductive coating | Electrical conductivity, surface-following property |
| Track pads | Foamed rubber | Shock absorbing performance at low temperature |
| Rolling stock, facilities, etc. | Sensors | Piezoelectric rubber | Exchange of electrical and mechanical energy |
| Analytical and mensuration technologies | Rolling stock | Contact interface in rolling bearing | Sensor sheets | Measures to prevent fretting damage of bearing |
| | Bearings | Measuring technology for forces acting on bearing cage | Improvement of bearing reliability |
| Facilities | Concrete structures | Water content in concrete | Clarification of correlation between water movement behaviors and concrete deterioration |
| Blast-furnace slag cement concrete | Compressive strength of surface concrete, concentration of calcium hydroxide | Optimization of neutralization rate evaluation |
| Rail surfaces | X-ray Fourier analysis | Quantitative evaluation of degree of rolling contact fatigue |

calcium to make it inflammable. However, there are still many aspects to be clarified, such as the basic characteristics and joining properties.

So far data has been collected on the manufacturing method and strength of flame-resistant magnesium alloy and its fracture characteristics have been investigated through fracture toughness tests and fractography [4]. Work will continue however to elucidate further its properties and other processes required for design based on the acquired insight.

2.3 Prevention of electrical pitting of bearings by application of grease with dispersed nanocarbon

Nanocarbon is the generic name for nanometer-scaled carbon materials. Some typical examples of this material are fullerene which has carbon atoms arranged like a soccer ball and bound each other, graphene which is composed of sheet molecules bound in hexagonal net, carbon nanotube which is a graphene sheet rolled up in a cylinder of a nanometer-order diameter and forms a hollow and tubular molecule, and carbon black which has a spherical form. Lately nanocarbon has started to gain attention as a new material having excellent mechanical characteristics and electrical conductivity.

Traction motor bearings may have to be replaced before their scheduled replacement because of electrical pitting, a type of surface damage attributable to the electric current flowing through the bearings, which is one of the factors causing a rise in the maintenance costs. There are two types of countermeasure to prevent this: bearing insulation and bearing energization. For traction motor bearings, insulated bearings are being introduced [5].

RTRI focused its investigations on the link between electrical pitting and electric current density in the bearing contact area and attempted to prevent electrical pitting by applying grease containing nanocarbon which is an excellent electrical conductor when used as an additive. The result of the energization rotation test using small bearings indicated that conductive grease with dispersed nanocarbon can prevent electrical pitting [6]. Thus nanocarbon was found to be useful for preventing electrical pitting.

2.4 Evaluation of wear properties of C/C composite pantograph contact strips

Contact strips made of carbon-fiber reinforced carbon (C/C) composite made by impregnating C/C base material with copper alloy are increasingly used because of their light weight, fracture toughness which is higher than the conventionally used carbon-based contact strips and ease with which they can replace metal-based contact strips. Their wear properties however need to be improved to ex-
tend their serviceable life cycle and ultimately reduce the impact of the high price of base carbon fiber. Wear tests and in-line trials clearly showed that the wear depth is proportional to the amount of energy discharged due to arcing if contact loss occurs frequently and to flowing current density when arcing is less frequent [7]. It has been also found that the thermal and oxidation properties and hardness of the base material and the wettability of impregnated copper alloy affect the wear property. Consequently, future work will aim to improve the performance in these respects.

2.5 Development of and recycling technology for piezoelectric rubber

Piezoelectric rubber is a piezoelectric ceramic material capable of changing electrical and mechanical energy reversibly and is mixed with rubber to offer flexibility. Piezoelectric performance decreases however if the two materials are simply mixed. Therefore, the material was molded by aligning the piezoceramic particles incorporated into the material to improve the performance. This allowed the material to reach the level of performance required for sensors [8]. In addition, investigations were conducted into the difference in pyrolysis temperatures of the ceramic material and rubber and proposed a recycling method for separating, recovering and reusing the piezoelectric particles from the used piezoelectric rubber.

2.6 Polymeric sheets for embankment slope protection by using non-halogen materials

RTRI developed slope protection sheets to prevent weed growth and collapse of embankments. Pressure over recent years to protect the environment however means that action had to be taken to modify current sheet materials because of the risk they posed to the environment when incinerated after removal. A polymeric sheet for embankment slope protection using non-halogen materials was therefore developed to overcome this problem [9]. The developed sheets do not use any halogen materials and are put in place installed without adhesives on the contact surface, which prevents delamination due to long use. This new material has now been introduced for use, since it was also proven to be more durable than conventional products and initial trials on a test embankment demonstrated basic performance criteria were met, dimensional stability and flame retardancy.

2.7 Movable nose crossings for Shinkansen lines

Among the crossings installed at rail intersections in turnouts, movable nose crossings with moveable nose rails (sharp-shaped head parts at one end) are made of high manganese steel with high anti-wear performance. However, they are difficult to examine using ultrasonic testing, making it impossible to grasp internal crack propagation. Under these circumstances, means were sought to use rail steel that allows ultrasonic testing. It was critical to make the rail head wear-resistant for the whole rail which forms a large section. Sufficient rail-head hardness was achieved by developing a heat treatment method [10].

In addition, a breakage detection method using a conductive coating was developed, to make it possible to check crossings built with high manganese steel for crack propagation. As the result of laboratory testing using cutout samples of a real rail and test specimens, it was made clear that at least cracks of a few millimeters could be detected by checking changes in the electrical resistance caused by breaks in the conductive coating due to cracking. The coatings can also be made to be durable over the long term and impact resistant. Thus it was confirmed that this technique could be used as a valid crack detection method [11].

2.8 Development of ballastless track for Shinkansen lines in cold regions

Ballastless track is considered to be an effective way to save on costs on Shinkansen lines, and a study has been conducted by performing cyclic loading tests etc. on real-size track models alongside development of elemental technology. However, freeze-thaw resistance needs to be improved for this type of track to be used in cold regions. The low freeze-thaw resistance and instability of pre-packed concrete used for track beds were thought to be caused by voids generated between the ballast and mortar and exposed aggregate on the end faces. A method was developed to prevent voids appearing by vibrating the ballast when being filled with mortar. Tests demonstrated that this method reduced voids by approx. 90 %, and the durability index found in freezing and thawing tests was stabilized as well. It was also confirmed that the required elastic performance of tracks was met by introducing low-elastic foamed rubber and hard rubber sleeper pads made of ethylene-propylene rubber between the sleepers and the pre-packed concrete track bed [12].

3. Research and development on analytical and mensuration technologies

Examples of RTRI work into material analysis and mensuration technologies are also summarized in Table 1. We have provided a quantitative evaluation index for any of the issues which were not able to be evaluated in a quantitative manner but were indirectly or sensuously discussed. This section introduces some examples.

3.1 Pressure distribution on the contact surface between axle bearing inner ring and backing ring

Fretting damage caused on the contact surface between axle bearing inner rings and backing rings produces microscopic metallic abrasive powder, which may enter the bearing assemblies and cause the bearings to wear out and/or degrade the lubricating grease. Inserting a ring-like part between the contact surfaces to prevent contact and infiltration of the abrasive powder into the bearing assembly is one measure which has been applied, but a more permanent measure to settle this problem needs to be found. One possible solution is to introduce a pressure distribution measuring system with a film-type sensor to ascertain the condition of contact area between the inner ring and backing ring. Checking the pressure distribution through
such a film-type sensor would clarify the relationship with radial loads on the bearings. Future work will explore measures to use new insights to prevent fretting damage [13].

3.2 Water movement at interfaces between concrete and repair materials and in surface concrete

Since the existence of water is often related to the deterioration mechanism in concrete, it is vital for more proper maintenance of concrete structures to clarify water movement behavior in concrete. RTRI is clarifying concrete deterioration through use of measuring technologies including the water content in concrete and the concentration of chloride ion. As a part of this study, water penetration on the surface concrete was investigated as were the interfaces between the concrete and repair materials applied for cross-sectional repairs, by using the concrete and mortar specimens fabricated with various combinations of mixtures and curing conditions. It was clarified as the result that good curing contributes to greater water penetration resistance while for interfaces with cross-sectional repair materials, the water penetration resistance varies greatly according to treatment methods employed before applying the repair materials. Investigations will continue into water movement behavior in order to build highly durable concrete structures and improve maintenance efficiency [14].

3.3 Evaluation of neutralization rate of blast-furnace cement concrete

Fine powder from blast-furnace slag produced as a by-product in the steel manufacturing process is increasingly used as a mixing material for cement in order to reduce the environmental load. Cases have been reported however, where structural neutralization behavior does not agree with the results of evaluation tests measuring accelerated neutralization. Concrete or mortar specimens were therefore prepared with various combinations of mixtures including fine powder from blast-furnace slag, and accelerated neutralization tests were conducted in curing conditions considering the actual environment and the testing conditions with varied carbon dioxide concentration, water supply etc.. The correlation between the behavior of and neutralization rate of the concrete was examined. It was clarified as the result that the effect on neutralization of using blast furnace slag fine powder in the actual environment is smaller than under accelerated test conditions and not much different from ordinary cement [15].

3.4 Application of X-ray Fourier analysis to evaluate the formation of rolling contact fatigue layers in rails

The formation of rolling contact fatigue (RCF) layers in rails due to rolling wheel contact causes shelling and other types of rail damage which in some cases may even lead to a rail breaking. In order to prevent RCF and remove RCF layers, it is critical to grasp the process of RCF layer generation. Experimental evaluation methods exist, such as metallographic observation, hardness measurements, and X-ray crystallographic analysis. However so far, none of these has succeeded in giving a quantitative evaluation of plastic deformation. As such a study was conducted applying X-ray Fourier analysis which utilizes information gained though X-ray crystallographic analysis in more detail. Reviewing the distribution of indexes acquired from rails in actual service and laboratory specimens showed that this analysis not only allows quantitative evaluation of abrupt changes in the metallographic structure near the surface of an RCF layer but also clarified that the change tended to be more significant towards the inside of the rail that at the surface [16]. Measurement data will continue to be collected and used to determine appropriate frequency with which rails should be maintained with grinding or replaced.

4. Conclusion

The regular progress achieved in the field of materials development for the railways at RTRI comes as a result of the synergy drawn from the Institute’s own developments and those brought in from outside. This work involves a broad range of issues: extension of serviceable life, improving efficiency and functionality, reducing the environmental load, replacing harmful substances, and increasing energy efficiency, which must all obey the overriding demand for safety. The purpose of this research is therefore to ensure that materials technologies will play their part in contributing to the development of a sustainable railway. It is hoped therefore that cooperation with other relevant parties will continue and grow and expand, in order to achieve this goal.

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