Recent Trends in Research and Development on Materials for Railways

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Progress in materials technology has led to many innovations, some of which can be applied to railways. In addition to the development of numerous materials and material technologies, advances in analytical and measurement methods have driven higher performance or improved the function of various types of equipment used on railway vehicles and facilities. Additional efforts now have to be made to adapt these new materials and technologies for practical application. This review describes some of recent results from research and development on the latest material technologies in RTRI including work to adapt these results for practical application in railway vehicles and facilities.

Keywords: materials for railway, achieve higher functionality, achieve higher performance, introduction, application

1. Introduction

Technological advances are often brought about not just through breakthroughs in design and construction techniques but also by materials that have a higher performance and functionality. This also applies to the railways, which have benefited from a range of material technologies. Examples include lubricants and the rubber used for hoses on vehicles, which now have a longer service life, helping to extend vehicle inspection intervals. Other examples include the development of slope protection sheeting with higher environmental acceptability which can be used on embankment slopes where previously other materials could not be used, because of regulations. These examples of progress are the result of advances in materials technology. Lubricant ingredients highly resistant to heat and oxidation were developed by oil and chemical industries in and out of Japan, which when applied in practice contributed greatly to extending the service life of lubricants. However, in order to decide which new material should be adopted, it is first necessary to clarify what factors have been limiting the service life of current materials. In the case of lubricants, the latest analytical technologies were used to clarify how lubricants reacted to factors that lead to deterioration, such as heat and oxidation. This case illustrates how progress in materials development goes hand in hand with new techniques to analyze deterioration and other phenomena affecting materials. RTRI has been engaged in both these areas.

Equally important to materials and analytical technique development is determining how best to introduce higher performance materials with improved functionality to railway vehicles and facilities into service. Even if a material displays an excellent performance and functions, if it is impractical, it has little chance of being adopted. This means technologies must be generated to facilitate the adaptation of developed materials for practical application.

This paper first describes a selection of materials research and development projects that have been adapted for practical application to resolve issues related to railway vehicles and facilities, it then discusses the results of these undertakings and finally, outlines prospects for the future.

2. Research and development on new material technologies and on their applications

Bringing new materials into use on railway vehicles and facilities involves not just research and development on the material itself but also often entails additional work to adapt the innovation into practice. This can involve anything from designing installation methods and replacement criteria to system development involving transmission of electric signals, wiring and tubing. Some research and development projects on materials and material technologies undertaken at RTRI which have then been the subject of additional work to adapt them for practical use, are listed in Table 1. From the items listed in the table, this paper describes three vehicle related projects and three facilities related (including power facilities) projects.

2.1 Development of piezoelectric rubber and its application to door operating equipment

Piezoelectric rubber is a sort of composite material, made by kneading piezoelectric ceramic particles, capable of converting electric energy into mechanical energy and vice versa, into rubber to produce material that has the elasticity of rubber. Kneading, however, reduces the piezoelectric performance of the ceramic. This can be overcome and piezoelectric performance enhanced by aligning the ceramic particles in an electric field while forming the mixture. Further successful work has been carried out to improve the performance of the material to the extent that the mixture can be used as a sensor.

As part of RTRI's related study on applying this material in a railway context, attempts are being made to apply piezoelectric rubber to pinch sensors on lateral sliding doors. This uses one of the advantages of rubber that it can be molded at will, and in this case into a thin strip measuring 5 mm in width and 1500 mm in length. This means this new material can be used to detect objects being pinched, that are smaller in diameter than those currently detectable with existing sensors [1].

There are a number of issues that need to be worked on further, including areas where detection is difficult,

Table 1 Examples of research and development projects on material technologies that have subsequently been worked on to adapt them for practical use

Category	Material / Materials technology	Application target	Technique for application
Vehicle	Flame-resistant magnesium alloy	Vehicle members, Body structures	Welding and evaluation methods
	Piezoelectric rubber	Door stop rubber	Signal transmission and control technologies
	Carbon fiber reinforced carbon composite	Contact strip	Low-cost manufacturing method
	Nanocarbon	Lubricating grease	Methods for improving conductive and mechanical properties, and electrical pitting evaluation method
	Lubricating grease service life extension technologies	Traction motor bearing	Non-disassembly grease replacement system
	Lubricating grease degradation evaluation technologies	Bearings for driving devices	Revision of grease evaluation criteria to check deterioration
Facility	Hardened geopolymers	Alkali silica reaction suppressor	Methods for application to railway facilities
	Non-halogen material	Slope protection sheeting	Installation method
	Conductive coating	System for detecting cracks on rails etc.	Data collection and evaluation methods
	Foamable rubber	Track pad	Method for evaluating shock absorbing performance at low temperature
	Superconductive materials	Feeders	Underlying technologies for cooling, stress mitigation, etc.

before the idea can be mainstreamed. These issues also include transmission of electric signals and door status detection control based on the received signal waveforms.

The application of piezoelectric rubber to door operating equipment requires the development of a comprehensive system entailing not just an improvement in the performance of piezoelectric rubber but also signal transmission and control technologies. Efforts will continue to achieve this goal.

2.2 Development of a flame-resistant magnesium alloy and its application to body structures

Among the highly effective energy-saving measures that exist in the development of vehicles is the reduction of body structure weight. The use of aluminum alloy to this end has proven to be very effective. Nevertheless, further reduction in weight requires new materials to be brought in.

Magnesium is lighter than aluminum, with only two thirds the density of aluminum. Magnesium alloy, however, is highly ignitable, which prevents it from being used in body structures. To overcome this problem, RTRI developed a flame-resistant magnesium alloy suitable for railway vehicle structures, made by adding calcium to the magnesium alloy. RTRI examined the basic characteristics of the flame-resistant magnesium alloy, including metallographic structure, mechanical properties and processability and, based on the findings, and studied ways to manufacture body structures using the alloy. As part of this work, hollow extruded prototype parts were produced using metal inert gas (MIG) arc welding and friction stir welding (FSW), selected for their low thermal impact on joining work.

Currently, experiments are underway on the possibility of using FSW to join hollow extruded pieces for body structures. Findings thus far have shown [2]: that welding tools need to be studied for appropriate materials and processing methods; that welded pieces need to undergo nondestructive inspection using ultrasonic waves etc. as they can develop

internal defects during the welding process; and that appropriate weld joint shapes need to be determined by analyzing the distribution of heat generated during welding.

Current plans are to produce prototype body structures using the material, which would then be tested for possible practical applications.

2.3 Lubricating grease service life extension technologies and evaluation criteria to check deterioration

Lubricants such as oil and grease are essential for roller bearings, which are widely used on driving devices, to rotate smoothly. Lubricants, mostly composed of organic compounds, deteriorate faster than bearings and other metal parts used on vehicles. For this reason, lubricants need to be replaced earlier than metal parts, and this can sometimes make lubricants one of the factors that determine the length of inspection intervals for vehicles.

There has been a demand for lubricants to last longer, which is being met by introducing new base oils and additives [3]. At the same time, the same lubricants could be made to last over a longer mileage using other ingenious measures targeting the environment in which they are used. RTRI therefore examined in detail the flow of the oil component of lubricating grease through the bearings and, based on the findings, proposed guidelines for designing the shape of the grease pocket adjoining the bearings that should help the lubrication process, as part of the investigation into how to extend the service life of lubricating grease [4]. In addition, a lubricating grease replacement system was developed that replaces grease in a grease pocket at intermediate intervals without the need for disassembly. Specifically, lubricating grease that is in direct contact with bearings is replaced at 25% of its service life, which extends the service life of the entire grease in the grease pocket. Bench tests confirmed that this method, the lubricating

grease in a grease pocket lasted a running distance equivalent to 1.8 million km on conventional lines [5]. This shows that RTRI has been active in improving not just grease but related systems, taking into consideration the characteristics of grease, to extend the service life of grease.

In order to ensure that lubricants are replaced at appropriate intervals, it is important to determine the degree of their deterioration. The R&D arm of the now-defunct Japanese National Railways proposed at the time a set of grease management standard values as a measure of grease degradation. The values have since then been widely used to determine the state of health of grease and the need for replacement. Over the years, however, there has been a growing need to revise these evaluation criteria as new types of lubricating grease with different deterioration properties appear in service, and as vehicle running conditions change. As such, lubricating grease used on vehicles was examined while other related action was taken to revise and bring the reference values up to date with current operating conditions. At the same time, a new analysis method was established to ensure the same analytical accuracy at all times [6].

The grease management standard values will be reviewed whenever appropriate by taking into consideration the technological context and the relevance of the values to vehicle running conditions at the time of revision.

2.4 Development of hardened geopolymers as a possible alkali silica reaction suppressor

Coal ash, a byproduct of coal-fired power generation, and blast furnace slag, a byproduct of a process in iron making where iron is extracted from iron ore, hardens when mixed with an alkaline solution. The resulting materials, or hardened geopolymers, have properties similar to those of cement concrete. As geopolymers release about 80% less CO₂ while being produced than cement concrete, they are being studied as a possible eco-friendly alternative to traditional cement concrete.

Hardened geopolymers are highly resistant to factors that cause cement concrete to deteriorate, such as alkali silica reaction and oxidative degradation. For this reason, hardened geopolymers could potentially be used where cement concrete cannot be used. As part of its work to clarify the characteristics of and establish manufacturing methods for hardened geopolymers, RTRI used fiber-reinforced hardened geopolymers to fabricate short sleepers, a type of sleeper typically used in underground railway tunnels prone to water leakage, and found that the sleepers offered a performance that satisfied the most stringent current specification requirements [7]. In addition, RTRI also produced hardened geopolymer sleepers meeting JIS 3 standards and has since been conducting tests on their installation on commercial lines with a view to introducing the sleepers into service.

Some hardened geopolymers have a cation exchange capability. Hardened geopolymers, a possible alternative to cement concrete, have a type called H⁺ geopolymers on which the sodium and potassium ions of the normal geopolymer have been replaced with hydrogen ions. As Type H⁺ geopolymers are known to have an ion exchange capability similar to that of zeolite, RTRI has been studying the possibility of using this type of geopolymer to adsorb cations, a contributing factor to alkali silica reaction. Capable

of preventing the pH of concrete from rising by releasing hydrogen ions and adsorbing sodium and potassium ions, Type H⁺ geopolymers are considered to be a promising candidate as an alkali silica reaction suppressor. RTRI has shown that it is possible to produce that type of hardened geopolymers, and has been clarifying their ion-exchanging characteristics. In its ongoing study on Type H⁺ geopolymers as a possible alkali silica reaction suppressor, RTRI has been trying to verify their capability to curb concrete expansion in comparative experiments with cement paste that does not contain Type H⁺ geopolymer additives [8].

Further studies will be conducted to manufacture and examine possible uses of the material to eventually offer it as a high-performance, low-cost alkali silica reaction suppressor.

2.5 Improvement of high temperature superconductive materials and their application to feeders

RTRI has been involved in the development of a whole spectrum of superconductive materials, which have zero electric resistance at and below certain temperatures, from synthesis and evaluation of materials to processing them into bulk and wire forms. Through this research, RTRI aims to develop DC feeders for practical applications.

The development of wire materials centers around rare earth (RE)- and bismuth-based superconductive oxides. Superconductive wire materials of yttrium (Y)-based oxide have a number of benefits including high mechanical strength and excellent energization characteristics in magnetic fields. However, they also suffer losses. RTRI aims to develop Y-based superconductive wire materials as well. In wire thinning experiments using third harmonic generation (355 nm) of a Nd-YAG laser in which wire materials measuring 10 mm in thickness were divided into a maximum of 20 pieces, it was found that thinner wires suffered lower losses in proportion to the number of divisions [9].

In RTRI's feeder development programs, efforts are also being made to develop the underlying technologies required for feeder installations on commercial lines.

One of the key components is cooling technology. Superconductive feeders need to be kept cool to stay superconductive. For this reason, related areas are being studied including cooling methods as well as circulation methods for liquid nitrogen which is used as the refrigerant. As part of this, a superconductive feeder system with an integrated cooling unit was installed on RTRI's test track to conduct a range of performance tests. Vehicle running tests conducted in the setup yielded successful superconductive power transmissions [10].

Feeders several hundred meters long shorten and lengthen in response to changes in temperature, which must be taken into consideration when installing and using feeders. RTRI introduced a method whereby the internal structure of feeders is examined using X-ray inspection apparatus. Using the method, short feeders were examined while being cooled for any change in their internal structure and, based on the results of the examination, a method was developed for mitigating stress in feeders while being cooled. Using those resources, cooling tests were conducted using liquid nitrogen on 300-meter class superconductive cables installed on the test track. The testing confirmed that those resources proved their ability to achieve the in-

tended mitigation of displacement and stress [11].

On high temperature superconductive materials, RTRI will continue its efforts to develop a range of technologies including those for manufacturing wire materials and systems required for introducing superconductive feeders onto commercial lines.

2.6 Application of conductive paint as part of a crack detection technique

To properly maintain the movable nose crossings made of high manganese steel installed on Shinkansen commercial lines, it is important to monitor the crossings for fatigue damage. With the movable nose crossing being a cast product, it is difficult to detect damage using ultrasonic inspection methods. Instead, visual inspections and impregnation methods are generally employed for that purpose. These methods, however, involve lifting the crossing and other operations that are time and effort consuming. To overcome this issue, RTRI studied ways to detect damage using conductive paint. Laboratory tests on cut pieces of actual rail and other test pieces coated with conductive paint showed that it is possible to detect cracks as small as a few millimeters by checking for changes in electric resistance caused by a broken or cracked conductive coating. The coating can be made resistant over the long term including against impact, increasing the possibility of it being used as a practical crack detection technique [12].

It is necessary to clarify the relationship between the electric resistance of a piece being measured and the length of cracks on the piece before the technique can be used on actual crossings. In addition, a data transmission system needs to be established to send and receive measured resistance. RTRI has been presenting proposals to railway operators of an entire system using the technique including a data transmission system. Going forward, RTRI plans to conduct durability evaluations on commercial lines.

3. Conclusion

RTRI's research and development activities on materials for railway applications cover a wide range of fields including: developing entirely new materials, clarifying issues and phenomena related to the use of developed materials, identifying appropriate applications for developed materials, establishing methods for controlling peripheral equipment to improve the performance of developed materials and develop methods for detecting signs of degradation. RTRI operates on the premise that work which goes beyond simply developing and introducing new material technologies, will lead to better exploitation of the potential

in material technologies that offer high performance and functionality. Tireless efforts to solve a range of challenges, including safety-ensured extension of service life, higher functionality, reduction in environmental load and higher energy efficiency, can ensure that technical innovations make a solid contribution to the further development of railways. As such, RTRI actively encourages and welcomes continuing support and suggestions from all interested parties.

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