Recent Trends in Research and Development on Materials Used in the Railways

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Technological development in various industrial fields including the railways has been brought about by advances made in component technology. Material technology contributes to component technology in many aspects. When developing materials, it is important to fully understand the properties of various kinds of material. One way to achieve this is to classify materials and gain a rough understanding of their properties. This paper classifies materials according to their compounds and/or components, and introduces aspects of materials research and development applicable to railway facilities and vehicles, depending on their classification.

Keywords: materials for railways, higher functionality, higher performance, introduced technologies

1. Introduction

Advances in technology are achieved by the development of underlying technologies as well as progress in design and construction technologies. This is also true for the railways. Improvements in material development and material processing technology have contributed to progress in many underlying technologies. Given the large variety of materials, it is important to fully understand their respective properties and determine how to use them, maintain them while in actual use, and replace and discard them periodically or when they are worn or damaged. If it is difficult to replace them or if they are only partially damaged, such materials will be repaired and to extend their life in service.

It is important to properly categorize materials to gain a broad understanding about them. Although different methods exist for categorizing materials by type, there are often three main categories: organic, inorganic and metal materials, depending on the types of substance or element that makes up the material. This categorization basically shows the right direction in terms of learning about the properties of materials, though there are exceptions. More detail about the three categories can be found in previous reports [1]. This report describes their respective features, introduces pieces of research and development relating to the different categories, and shows the current and future direction of work. On the other hand, there are also many cases of using composite materials produced by a mixture of different materials thanks to the development of material technologies in recent years. This report introduces these materials as well.

2. Current situation relating to technological developments by type of material used

Table 1 shows RTRI research and development grouped into three categories: organic, inorganic and metal materials. The current status and future development for some cases are also described below.

2.1 Organic materials

Organic materials are composed of organic compounds containing combinations of carbon as the main component, along with hydrogen, oxygen, nitrogen and other elements. An organic material can be in any state of matter - solid, liquid or gas according to the number of carbon atoms that constitute the material. Organic materials are used in the railways as well as in other industries, in a variety of forms, such as oil, rubber and plastics. Compared with inorganic and metal materials described later, organic materials tend to deteriorate more rapidly, depending on the environment. Therefore, when using organic materials it is important to inspect and replace them accordingly.

2.1.1 Gear oil for Shinkansen rolling stock

In gear units for electric trains, lubricant called gear oil is used to lubricate the engagement faces of the gears and the bearings on the both sides of the gear and pinion respectively, in the gear unit that transmits the rotations of the traction motor to the axles and wheels.

Many lubricants including gear oil are organic materials. Recent years have seen a lengthening of the interval between general inspections and inspection of important parts. Consequently, there is a demand for longer serviceable life of these products, that can withstand the extended replacement cycles, and also, to provide proper solutions to more severe working environments.

Gear oil is expected to perform in several ways in addition to lubricating performance. Fluidity at low temperature is one of them. Generally, as the temperature of a lubricant falls, its viscosity rises. Accordingly, gear oil that falls into the oil sump at the bottom of the gearbox is not sufficiently drawn up, especially in certain conditions, such as starting up in winter. As such, bearing seizure at low temperature due to insufficient lubrication must be prevented, especially in the pinion bearings away from the oil sump. One countermeasures is to reduce the viscosity of gear oil at low temperatures. Nonetheless, to maintain sufficient lubricating performance across a wide range of
temperatures, viscosity needs to remain high enough to retain the required thickness of the lubricant film. Hence, oil is required, because it has a viscosity that fluctuates only very little with temperature.

RTRI therefore selected a material with a viscosity that increases less at low temperatures than the current gear oil and yet is sufficient to form a lubricant film across a wide range of temperatures and does not significantly increase production costs. This material was then used to develop a new type of gear oil. A prototype oil was prepared using a mineral oil that was much more refined than before as a base oil, to which new types of additives were incorporated.

Results from laboratory tests demonstrated that the prototype gear oil’s viscosity and other properties, and its lubricating and other performance requirements, met the target specifications. It was therefore subjected to further trials on a test bench followed by on-track verification tests. The railway vehicle using this gear oil has so far run 580,000 km at the maximum running speed of 320 km/h, and no problems with the gear oil have so far been observed [2].

2.1.2 Development of sensing technologies using piezoelectric rubber

Piezoelectric rubber is a material produced by mixing and kneading rubber and piezoelectric ceramics particles. And it is capable particles. And it is capable of converting electric energy into mechanical energy and vice versa. The defining feature of this rubber is that it is both as flexible as rubber and has piezoelectric performance. Mixing an inorganic piezoelectric material into rubber, an organic material, enables us to make use of each material’s respective

| Category               | Application | Material(s)                  | Target application                          | Recent work                                           |
|------------------------|-------------|------------------------------|---------------------------------------------|------------------------------------------------------|
| Organic materials      | Equipment   | Non-halogen material         | Slope protection sheeting                   | On-site installation method                          |
|                        |             | Foamable rubber              | Track pad                                   | Improvement of shock absorbing performance at low temperatures |
|                        |             | Resin                        | Acoustical panel                           | Improvement of sound absorbing performance and workability |
| Rolling stock          | Piezoelectric rubber | Door end rubber              | Signal transmission and control technologies |
|                        | Nanocarbon  | Lubricating grease           |                                              | Improvement of electrical conductivity and mechanical properties |
|                        | Resin       | Window glass                 |                                              | Determining deterioration                            |
|                        | Oils and fats| Lubricant oil and grease     |                                              | Extending serviceable life and environmental acceptability |
| Inorganic materials    | Equipment   | Hardened geopolymers         | Sleepers, etc.                              | Evaluation of durability                             |
|                        | Concrete     | Bridges and other structures | Methods for application to railway facilities |
|                        | Superconductive materials | Feeders                        | Cooling, stress relaxation and other underlying technologies |
| Rolling stock          | C/C composites | Contact strip               |                                              | Cost reduction and clarification of wear limit thickness |
| Metals                 | Equipment   | Steel materials              | Rail                                        | Quantification of rolling contact fatigue            |
|                        | Rolling stock | Roller bearings             | Insight gathering into factors affecting rolling element load |
|                        |             | Wheel                        |                                              | Wear factor detection and wear prevention            |
|                        | Flame-resistant magnesium alloy | Vehicle members and body structures | Welding and evaluation methods |
| Organic/ inorganic/ metal | Equipment | Resin, metal particles, etc. | Paint                                       | Surface preparation for repainting and LCC (life cycle cost) evaluation |
| Inorganic/ metal       | Rolling stock | Ceramic particles, etc.      | Wheel/rail friction modification           | Safeguarding performance in the presence of leaves on the tracks |

Table 1 Components used in the railways by material category, and description of recent related work
features.

The issue with this material was the decline in piezoelectric performance, compared with the original piezoelectric ceramics. However, it is now clear that piezoelectric performance can be improved by orientating the piezoelectric particles, in other words, aligning the direction of polarization. In addition, RTRI is researching and developing various sensing technologies using piezoelectric rubber.

For door end rubber sensors with built-in piezoelectric rubber, it was made clear that foreign objects as thin as about 10 to 15 mm in diameter which had been difficult to detect were now detectable. RTRI has also designed and produced transmission and control systems incorporating them into existing side sliding door operating systems and is now close to introducing the technology into service.

Damage to axle bearings can lead to serious accidents. Therefore, it is necessary to be able to detect damage at an early stage. Tests were carried out to detect bearing defects with piezoelectric rubber using it as a sensor in the rubber vibration isolator between the axle box and the axle spring demonstrating that it was possible to detect abnormal vibrations during rotation. A bearing was given an artificial defect and was rotated, while piezoelectric rubber with aligned PZT particles was used and was stacked, to improve its performance. Bench test results showed that it was possible to detect bearing damage which hitherto had been difficult to detect using the conventional method of detecting a defect from temperature. Additionally, it was possible to detect signals corresponding to defects even during running tests using an actual vehicle on RTRI’s in-house test line [3].

2.2 Inorganic materials

Inorganic materials are materials composed of inorganic compounds. Since inorganic compounds are defined as “compounds other than organic compounds,” they include a great many compounds and composite materials. A typical inorganic material is ceramics made by forming and baking powders, etc., which are used as insulating materials, for example, in insulators. Some materials can become superconductive with an electrical resistance of zero, when at low temperatures. Cement, a constituent material of a concrete structure, is also a sort of ceramic, for which research and development in the field of inspection and repair technologies is critical.

2.2.1 Cracks in concrete structures in cold regions

Frost damage is one phenomenon which causes concrete to deteriorate, whereby a given quantity of water contained in the concrete is repeatedly frozen and thawed due to changes in outside air temperature or because of solar radiation, causing the concrete to gradually deteriorate from the surface.

In one case surface discoloration was discovered on the concrete in a cold region. When the concrete cores were checked, horizontal cracks were found inside, though there was no noticeable deterioration on the surface. In frost damage, delamination often occurs on the surface layer. However, there was no such defect in this case. Furthermore, no deterioration that could cause cracks inside concrete, such as alkali silica reaction, was observed.

RTRI classified the case as non-conventional frost damage and conducted tests and investigations. The result of these tests indicated that the air void spacing factor in the concrete in question was large, as a whole, with a smaller air volume mainly in the area showing discoloration, which would indicate lower frost damage resistance. A test to simulate temperature cycles reproducing fluctuations in upper surface temperatures caused by snow accumulating and then melting, was carried out on lower surfaces that are most affected by changes in outside air temperature. The tests was conducted on concrete specimens manufactured with different air volumes, curing conditions and air void spacing factors. The results showed similar horizontal cracking had occurred in the actual structures in specimens that had been given smaller air volumes [4].

Based on these findings, methods can be proposed to ensure sufficient maintenance and management, such as preventive measures and methods to repair structures and protect them against this type of concrete deterioration in the future.

Concrete is a material made from a combination of cement and aggregate, for which clarification of the new deterioration mode as in this case is one of the critical issues. For fundamental clarification of the deterioration, it is necessary to consider the existence of water and salt contained inside and outside concrete and even the corrosion of rebars.

2.2.2 Improving the properties of and applications for high-temperature superconductive material

RTRI has been involved in a whole spectrum of research and development involving superconductive materials, which have an electric resistance of zero when cooled down to certain temperatures: synthesis and evaluation of materials and processing into bulk and wire forms. Moreover, RTRI has tried over recent years to apply these technologies to actual DC feeder cables for use in service [5].

Other applications for these types of material, such as niobium-titanium (NbTi) are currently used for superconducting magnetic energy storage (SMES) devices which are being developed as electrical storage devices for railways. Though they are high in stability and reliability, the refrigerant, liquid helium, used to cool them to a superconducting state, is expensive, creating a high-cost issue. To resolve this problem, RTRI is involved in developing magnesium diboride (MgB$_2$) wires which require materials that are inexpensive and easy to source. This new development is also expected to reduce the cooling cost because the superconducting transition temperature for this material is 39 K, higher than for conventional materials.

The Institute is aiming to develop several 10 kJ class coils necessary for application to electrical storage devices for railways. The Institute has established coil specifications required for this purpose, evaluated the properties of MgB$_2$ wires as an underlying technology, developed winding and stranding techniques to form a coil shape and evaluated the characteristics of the power storage coils obtained through the above processes.

On the basis of the characteristics found in this way,
RTRI aims to develop coils for large-capacity power storage devices which are expected to be applied to power storage for railways, including designing and fabrication of several 10 kJ class large coils in the future [6].

2.2.3 C/C composite pantograph contact strips

Pantograph contact strips can be roughly categorized into two types: One of them is metal-based, and the other is carbon-based. Carbon-based contact strips are made of composite materials combining carbon and copper. They have high self-lubricating properties and are capable of reducing contact wire wear, which were the reasons for this material to be so widely used. Carbon fiber reinforced carbon (“C/C”) based contact strips are produced in a way which allows them to be fastened with bolts to the pantograph heads like metal-based contact strips. Such C/C based contact strips have higher toughness by virtue of the composite fibers, compared with carbon-based ones.

C/C composite pantograph contact strips therefore offer the advantages of carbon based contact strips, and offset the disadvantages of simple carbon-based strips with the added carbon fibers: cost of using however was an issue. This study therefore reviewed the manufacturing process and minimum admissible wear thickness, experimentally. As a result, manufacturing costs were reduced by about 20%, and the minimum thickness was calculated considering proper fastening force based on the relationship between the remaining thickness of contact strip area used for fastening, and the axial force on bolts used to fasten the contact strips to the pantograph head [7].

Although this report initially described materials containing carbon as organic, if the material consists of simple carbon substances, they are often categorized as inorganic. Accordingly, this report classified these carbon-based contact strips, as inorganic.

2.3 Metals

“Metals” means materials composed of metal elements, typical examples of which are iron, aluminum and copper, etc. According to the definition of inorganic compounds given above, they therefore fall into the inorganic material group. Since metals are generally strong, tough and heat resist, etc., they are often employed to make parts that must withstand heavy loads or be rotated, and for mechanical elements: mainly members around body parts that must withstand heavy loads or be rotated, and furthermore, the change in the maximum rolling element load distribution differed according to the axial clearance even if the radial loads were the same, and furthermore, the change in the maximum rolling element load varied according to the dimensions of the axial clearance [9].

The main material component of the bearings used for these investigations, was bearing steel, i.e., a metal material. This study was aimed at improving the reliability of roller bearings by gaining more accurate insight into the forces acting on the materials, in addition to insight about the materials themselves.

2.3.1 Application of flame-resistant magnesium alloy to vehicle body structures

Reducing the weight of train vehicle body structures is critical for energy-saving. Many vehicle body structures today are built using aluminum alloy. Employing lighter weight magnesium would make it possible to further reduce the body weight.

RTRI is currently working on the application of a “flame-resistant magnesium alloy,” which has suppressed ignitability because of calcium added to the magnesium alloy, which is used in vehicle body structures. RTRI investigated the basic characteristics of this alloy, such as its microstructure, mechanical properties and workability, then prototyped a hollow extruded material, and also recommended the use of metal inert gas (MIG) welding, a type of arc welding, and friction stir welded joints, to minimize the thermal effect when joining parts that is dispensable in manufacturing body structures.

The feasibility of the body structure assembly was evaluated on the basis of the data accumulated to date. MIG welding was applied to the prototyped hollow shape material, from which a small, half-section model of a body structure was made. New findings were obtained from that process, such as the need to devise the order of junctions or assemblies between shapes [8].

Further study however is required into joining technologies and surface treatment methods to be able to use this alloy in service.

2.3.2 Factors affecting rolling element load on roller bearings

Axle bearings are critical components in railway rolling stock that connect the axles to the bogies and keep the axles rotating smoothly while receiving the loads of the vehicles and those induced by vibrations. The rolling contact fatigue life for roller bearings is calculated theoretically. In order to gain more precise insight into rolling contact fatigue life, however, it is necessary to know the distribution of the rolling element loads inside the bearings, that is, the loads shared by the individual rolling elements. RTRI has devised a method to measure the rolling element loads by inserting an optical fiber sensor into a rolling element of a measuring bearing and has clarified the distribution of rolling element loads on the various roller bearings.

RTRI studied the effect on the rolling element load of double row tapered roller bearings widely used as axle bearings, of changes in axial clearance, which is the clearance in the axial direction of the bearing. The findings included the fact that the maximum rolling element load and the rolling element load distribution differed according to the axial clearance even if the radial loads were the same, and furthermore, the change in the maximum rolling element load varied according to the dimensions of the axial clearance [9].

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3. Summary

The technological development of materials for railways at RTRI includes both organic and inorganic materials, and metals. The scope of this research and de-
Development is broad, and encompasses maintenance and management methods to optimization of use, which all require clarification of phenomena affecting these materials. The scope of this work also includes studying appropriate applications, in addition to development of materials themselves. The aim of these investigations is to contribute to the sustainable development of the railways from a material technology point of view. The author of this paper encourages support from JR and other railway operators, universities, manufacturers and academic societies interested in this field of work.

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