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Materials and Technologies for EV and Open Innovation Strategy in JFE Group

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Abstract:

Material innovation has been required from the realization of Society 5.0 and the achievement of SDGs. JFE Steel has been developing a wide variety of functional materials since 1980s. These materials commercialized by JFE Group companies are used for batteries and electronic devices. In addition, these companies possess the analysis and the evaluation technique and the environmental recycling technology, which are expected to contribute to the four major automobile trends 'CASE', including electric vehicle. On the other hand, the Ministry of Economy, Trade and Industry has positioned the material industry that manufactures functional materials as Japan's leading industry. For the sophistication of material innovation, it is focusing on the open innovation that achieves the quality and speedup of material development, and the strengthening of the creation and proposal capabilities of new materials that bring about social change from the material side. This paper outlines the materials and technologies for EV in JFE Group, and explains the role of Functional Material Research Department, which was established to strengthen cooperation with Group companies from the perspective of open innovation.

1. Introduction

Dr. Akira Yoshino, an Honorary Fellow of Asahi Kasei Corporation, received the Nobel Prize in Chemistry in 2019 for his development of a lithium ion battery. About half of the 24 Nobel laureates in the field of natural science in Japan were awarded for material-related research, and the research achievements recognized so far are noteworthy for leading to major social changes through social implementation, as seen in Esaki diodes, blue light-emitting diodes, and conducting polymers.

Materials and automobiles manufactured in Japan are the core of the country's export industry, accounting for more than 20 % of the total export value, and many materials hold the majority share of the world market for its constituent materials. On the other hand, many papers are published in material-related fields such as materials science in Japan, and enjoy high international competitiveness compared with other fields. Japan has high quality research centers and researchers that can compete at the world level, and the existence of world-class research facilities and research equipment and high quality material data can be considered large strengths.

Material innovation is required from all fields for realization of the concept Society 5.0 of the future society which the Japanese government advocated in the 5th Basic Plan for Science and Technology in 2016, achievement of the SDGs as a common goal of international society, formation of a human-centered inclusive society, and countermeasures for the novel coronavirus pandemic, which is currently having a great impact on the global economy and society. Against this background, the Ministry of Economy, Trade and Industry (METI) has positioned the material industry as a leading industry in Japan, and has begun to make serious efforts to nurture and develop the industry.

NKK and Kawasaki Steel, the predecessors of the JFE Group, positioned new businesses as the core of their growth strategies in the latter half of the 1980s, and invested management resources in ceramics, polymer materials, metal materials, etc. in order to develop the conventional new material business into a high added value development-type business[1, 2]. Among these new material businesses, the materials which survived by overcoming the three barriers called "the river of evil," "the valley of death," and "the sea of Darwin" have begun to show their presence in the automobile field, which has now entered a large, once in 100 years age of innovation. As shown in **Fig. 1**, materials for

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Fig. 1 Examples of functional materials by Group companies

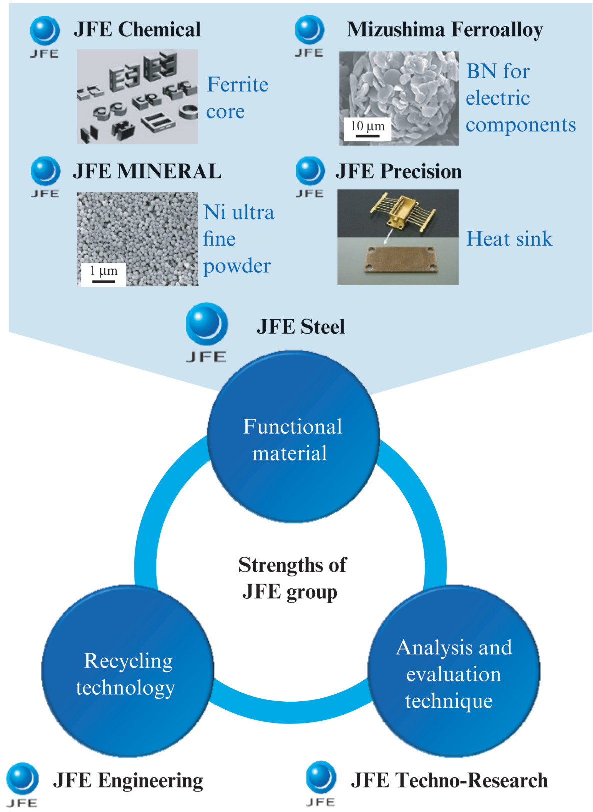

Fig. 2 Strengths of JFE Group for EV

batteries and electronic devices are expected to contribute to the four big trends “CASE,” beginning with the conversion to electric vehicles (EV).

This paper presents an outline of products and technologies of the JFE Group that support EV, and describes the role of the Functional Material Research Department, which was created recently to strengthen cooperation with group companies, from the viewpoint of open innovation.

2. JFE Group Products and Technologies Contributing to the Conversion to EVs

2.1 EV-Related Products and Technologies

In addition to the functional materials as shown in Fig. 1, the strengths of the JFE Group include analytical evaluation technology and resource recycling technology, as shown in **Fig. 2**, which contribute to EV in various forms. This chapter introduces EV-related products and technologies of JFE Steel Group companies.

2.2 JFE Chemical

JFE Chemical manufactures and sells chemical products, battery materials, precision chemicals, and magnetic materials produced from by-products such as coal tar, gas, and iron oxide generated in the process of manufacturing steel products (**Fig. 3**).

In addition to products made from by-products of the iron and steel manufacturing processes, plastic moldings made from raw materials procured externally are also manufactured and sold by a subsidiary company, K-plasheet Corporation.

At present, the development of the four fields of functional chemicals, namely, battery materials, precision chemicals, magnetic materials, and plastic moldings, is mainly promoted for the growth markets of 5G, EV, and especially “CASE.”

In battery materials, JFE Chemical has developed negative electrode materials for lithium ion secondary batteries by combining an original reforming technology using coal tar pitch as a raw material. The company has introduced spherulite graphite, natural graphite, and hard carbon on the market, and is promoting application to the mobile, HEV, and EV fields according to characteristics such as energy density and output density, together with further performance enhance-

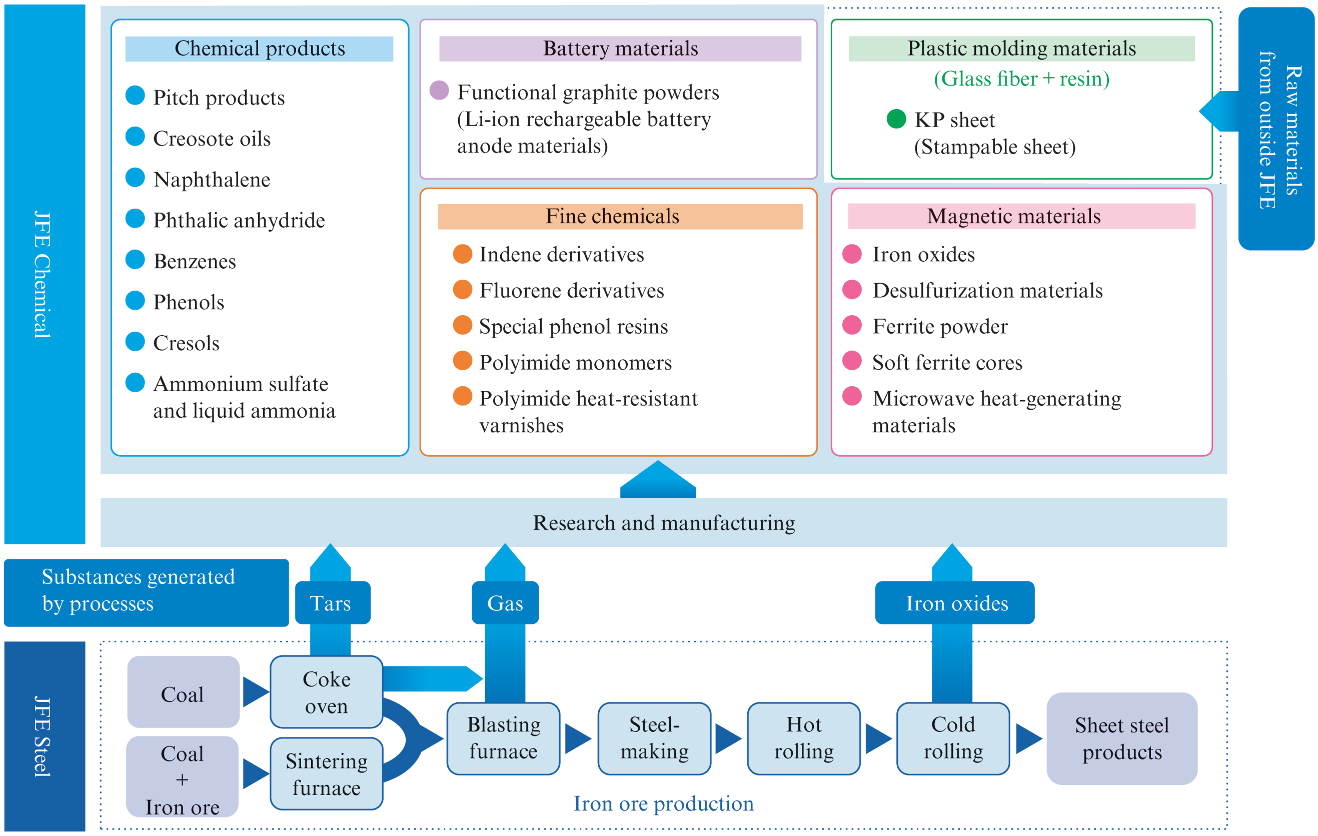

Fig. 3 Business of JFE Chemical

ment. Among these materials, utilization of hard carbon, which is a unique "Only One" product, as a negative electrode material for all-polymer batteries (APB)[3] is also under examination.

In precision chemicals, electronic materials and high-functional resins have been developed from chemicals containing five-membered rings such as indene and fluorene, which are peculiar to coal type substances, among the useful components contained in coal tar. These products are widely used as raw materials for optical functional materials, represented by films for liquid crystal displays and lenses for smartphones.

In magnetic materials, JFE Chemical developed a MnZn type soft ferrite core which is widely used in power supply transformers, choke coils, noise filters, antennas, etc. The main raw material of this product is iron oxide recovered from waste acid generated by dissolving and removing iron oxide films during surface cleaning with hydrochloric acid in the cold rolling process. Taking advantage of its world's Only One strength in integrated manufacturing from iron oxide, the company is developing various products, mainly for automotive applications.

Plastic molding is a sheet-like molding base material for press use made from glass fiber and polypropylene, a thermoplastic resin, as the main raw materials. Because this product contains a special foaming material, it displays extremely high expansion performance when heated and can also be laminated with a diverse range of functional films. Therefore, it has been widely adopted as a stampable sheet with light weight, high rigidity, and high sound absorption features as an automobile interior material for parts such as ceilings and trunk trim, and as an automobile exterior material for under cover parts. Targets for future product development include automobile weight reduction, etc.

2.3 JFE MINERAL

JFE MINERAL was originally established as a mining business to mine and process submaterials such as limestone and silica, which are indispensable in the steelmaking process, and is currently engaged in recycling of steelmaking by-products such as slag and the soil environment purification business. This company is also developing its own functional materials business utilizing the technologies cultivated in these businesses.

JFE MINERAL successfully produced ultrafine nickel powder in an industrial mass production process by CVD (chemical vapor deposition) for the first time in the world. This powder is mainly used as an internal electrode material for multilayer ceramic capacitors (MLCCs), and has been highly evaluated by the electronic component industry. The number of MLCCs used per EV has now reached 10 000 with the progress of electric equipment in automobiles, IoT, and 5G. The company is also energetically developing new ultrafine powders which will contribute to further performance enhancement of electronic components.

Potassium titanate (TIBREX®) developed by this company is used as a friction material for automotive brake pads. Nickel-cobalt-lithium aluminate (NCA) cathode materials developed by applying this complex oxide manufacturing technology have contributed to higher performance in power tools such as electric power tools and vacuum cleaners, digital cameras, unmanned aerial vehicles, etc. as cathode materials for lithium ion secondary batteries featuring high capacity, high safety, and high cycle characteristics. In order to respond to needs for further capacity upgrading in recent EV, etc., development of an NCA positive electrode material with an increased nickel mixing ratio is also a current focus.

PMN-PT piezoelectric single crystal produced by the original "raw material continuous supply Bridgman method," which originated from the development of MnZn ferrite single crystal for VTR heads, is used in the ultrasonic probes of ultrasonic diagnostic equipment for advanced medical use, and its uniform quality has been highly evaluated by users in Japan and overseas. The PIN-PMN-PT piezoelectric single crystal, which is made by adding an indium compound to this pseudo-binary composition to improve durability in high-temperature and high-voltage environments, is being studied for application to submarine sonars and actuators, as well as medical ultrasonic probes, and is expected to be applied to EVs.

2.4 Mizushima Ferroalloy

Mizushima Ferroalloy was established as a group company of Kawasaki Steel to manufacture ferromanganese, which is used for deoxidation and desulfurization in steelmaking process.

"BN Leaf Powder®" is a scale-shaped boron nitride (BN) powder for cosmetics, and has received high evaluation from users for it synthesis technology, which provides safety and various functions, and powder processing technology, which realizes a wide range of sizes and surface characteristics.

Aggregate BN was developed by applying a stable synthesis technology for aggregated grains in an ultra-high temperature, high pressure atmosphere. BN is widely used in electronic component applications such as power modules because it has excellent thermal conductivity and insulating property.

2.5 JFE Precision

Like Mizushima Ferroalloy, JFE Precision was originally established as Niigata Works of NKK to produce ferromanganese. As a result of a subsequent restructuring of its business operations, the company now produces functional materials utilizing powder sintering technology and ion plating.

As materials utilizing powder sintering technology, the company developed a chromium copper heat sink material which has been applied practically in electronic components, and high expectations are also placed on a molybdenum copper type with excellent thermal characteristics.

In ion plating, JFE Precision developed a technology which forms a hard film based on metal nitride on the surface of cutting tools and dies, and has a product line-up which makes it possible to propose the optimum film corresponding to the application, thereby contributing to longer tool life.

2.6 Nippon Chuzo

Nippon Chuzo was established in 1920 by Soichiro Asano, the father of Keihin Works of NKK, and originally manufactured cast parts for shipbuilding. Afterwards, its businesses expanded to cast parts for construction machinery. With the strengths of an integrated manufacturing system and original equipment, the company offers various types of castings for a diverse range of industries. Its extensive track record includes bridges for the Tokyo Monorail and structures such as Tokyo Skytree. It is also developing materials with various types of performance, such as heat resistance, corrosion resistance, and abrasion resistance, including the low thermal expansion material "LEX®" which suppresses dimensional change by temperature change. Nippon Chuzo developed the world's first zero thermal expansion alloy "LEX-ZERO®" in 2014, and in 2020, it announced the zero thermal expansion coefficient alloy "LEX -3DP®", in which the cobalt content was reduced to the absolute minimum by utilizing three-dimensional lamination molding (3D printer).

2.7 JFE Techno-Research

JFE Techno-Research is a comprehensive technical support company which performs analysis, testing, evaluations, and investigation and research related to various materials, products and parts, including iron and steel. Its object materials span a diverse range not limited to metals, but also including resins and composite materials, medical supplies, implant materials, magnetic materials, electronic devices, secondary batteries, and solar cells. In many cases, JFE Techno-Research conducts technical problem solving work in cooperation with JFE Steel.

As an EV-related project which was carried out in cooperation with JFE Steel, the creation of a prototyping and evaluation system for sulfide-type all solid state battery supported by the Functional Material Research Department of the Steel Research Laboratory in August 2020 may be mentioned. As a result, an integrated contract system from battery prototyping to battery characteristic evaluation and testing, and analysis and examination of battery materials was constructed, as reported in a separate article in this issue of JFE Technical Report.

3. Role of Functional Materials Research Department, Steel Research Laboratory

In October 2017, JFE Steel established the Functional Material Research Department within the Steel Research Laboratory to promote the development of functional materials for growth fields through collaborative innovation activities by fusing the core technologies of group companies with the basic technologies of the Steel Research Laboratory (**Fig. 4**).

In collaborative innovation activities with group companies, it is important to create an organization that can utilize the strengths of members and organizations by making the organizational walls as low as possible. Therefore, in the Functional Material Research Department, researchers and engineers were brought together from the Steel Research Laboratory and group companies, and a system for carrying out research and development was constructed by the researchers of the Steel Research Laboratory and persons loaned from group companies. In work on battery and magnetic materials, cross-company working group activities with the participation of group companies are planned and promoted in order to permeate a consciousness of cooperative creation through a wide layer. As part of these activities, EV Parts Investigation & Report meetings (**Photo 1**) are held jointly with group companies in order to find out and select potential cross-company themes.

In selecting themes, referring to the demonstration research on new businesses carried out by Kawasaki Steel in the 1980s[4] and the strategy of functional material manufacturers who successfully restructured their businesses, it was decided to aim at the development of functional materials in a region which will not become a technical enclave, that is, by starting from our own technologies, and not introduced technologies, while also considering the viewpoint of SDGs and ESG. As an example, **Fig. 5** shows the scope of responsibility in the EV field. Among the “Three Sacred Treasures” of EV, the following were adopted as targets of research:

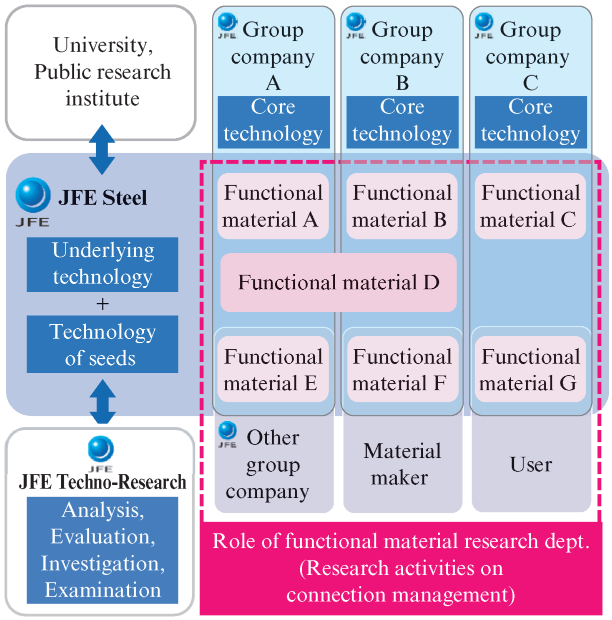

Fig. 4 Role of Functional Material Research Dept.

Photo 1 JFE Group joint report meeting of EV parts survey

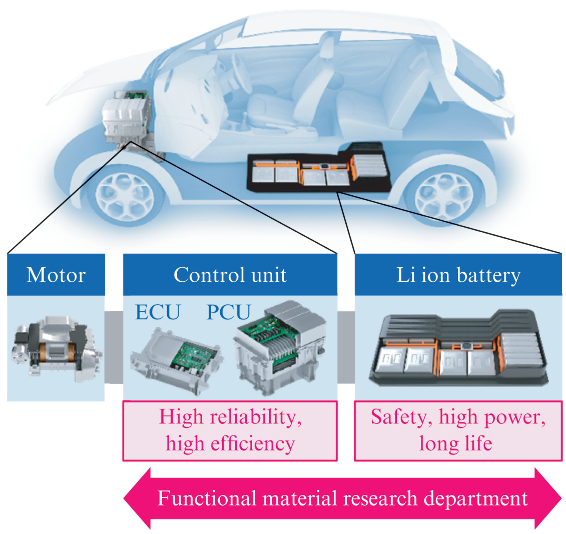

Fig. 5 Scope of responsibility of Functional Material Research Dept. in EV field

Materials for passive components such as ferrite, which is frequently used in control units, heat radiation materials, and positive and negative electrode materials for Li ion secondary batteries.

The Steel Research Laboratory also encourages leading exploratory research activities such as verification, trial and error, and tasting experiments of advanced ideas, which are carried out based on the free ideas and proposals of researchers and nurture the buds of future epoch-making products and innovative technologies. Since the results of this kind of research include no small number of products and technologies which are buried without finding an exit in the steel field in spite of their high originality, the Functional Material Research Department was also given the function of an incubator to “match and hatch” those products and technologies with various materials and processes targeted by the Functional Material Research Department.

However, it is difficult to achieve commercialization by rapidly and effectively promoting these tasks with only existing resources and conventional strategies. For this reason, open innovation is positively utilized in order to lead to new markets and innovation creation by introducing external resources, opening internal resources, and cooperating with external organizations.

Figure 6 shows the types of outputs targeted by the Functional Material Research Department based on the conceptual diagram[5] proposed by Dr. Henry Chesbrough, who advocated open innovation. The Functional Materials Research Department (“A” in Fig. 6) fuse elemental technologies and seed technologies cultivated in steel research with the own technology of a JFE Group company (“B” in Fig. 6) and an outside technology (“C” in Fig. 6), and set the research theme of “Problem solution type I” and “Problem solution type II,” aiming at commercialization at group companies or outside companies, as the main theme for the present. These themes were carried out through personnel exchanges and training between JFE Steel and its group companies with the aim of creating successful cases as early as possible. “MnZn Ferrite with Higher Strength,” which is described in another article this Special Issue, is a typical example of “Problem solving type I”. In order to demonstrate the incubator function mentioned above, research is also oriented toward the “New value creation type,” which aims at commercialization through collaborative innovation activities with startup companies, and “Needs search type,” which returns the knowledge obtained through these three types of open innovation activities to the steel field. Results of all of these types of research are already beginning to appear.

Although these challenges become a mechanism which produces “new knowledge” by a combination of “existing knowledge” and “existing knowledge,” “exchange of knowledge” is necessary for the innovation. To enable knowledge exchanges, the Functional Material Research Department issues a newsletter called “CROSS F” to widely introduce the department’s strategy and results to JFE Steel and other business companies. The logo of “CROSS F” is shown in **Fig. 7**. “CROSS” means an attitude of tackling new areas not limited to existing technologies, methods, and fields together with group companies, and “F” is an attitude of enjoying (Fun) the development of functional (Function) materials by working together (Fusion), and playing roles (Function) based on fundamental principles (Fundamental). It also includes an intention to search for “catchers” who will receive the “new knowledge” thrown in by the Functional Material Research Department.

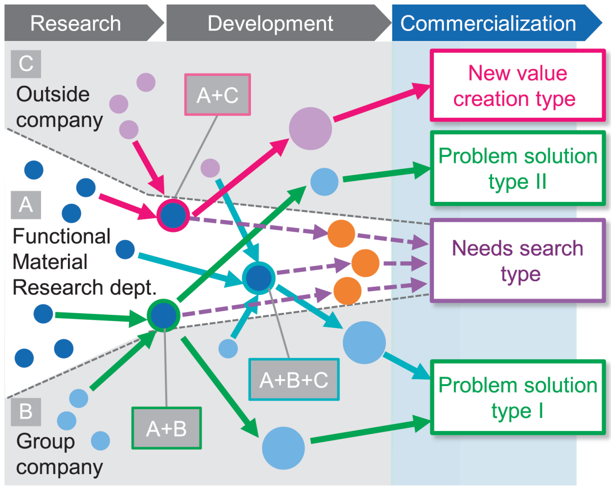

Fig. 6 Output type of Functional Material Research Dept. from open innovation perspective

Fig. 7 Logo mark of Functional Material Research Dept. news ‘CROSS F’

4. Conclusion

Joseph Schumpeter, an economist who preached that “innovation by enterprises brings about economic growth,” stated in his book that “no matter how many mail coaches you connect, you cannot get a postal railway."[6] That is to say, Schumpeter proposed that repeating the same thing many times does not lead to essential change, but rather, radical innovation is realized only by introducing a heterogeneous new thing. This "introduction of a heterogeneous new thing" is called "new combination," and the action which creates that " heterogeneous thing" is expressed as "innovation". The Functional Material Research Department strengthens open innovation as the "Dejima" of the JFE Group, and it also focuses on the developing talent with high "judgment ability." By taking on the various challenges described in this paper and cultivating a consciousness of cooperative creation with partners inside and outside the company, we intend to enhance "new combinations" in order to promote material innovation.

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