History and Future Prospects of Magnet Wire Development

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In 2016, it was 100 years since Sumitomo Electric Industries, Ltd. first produced its enameled wire. The magnet wire, coated with an insulation film, has been used in various products including electrical components, household appliances, and electrical conductors, and supported the industry. This paper outlines the history of magnet wire from development to commercialization over the century and introduces our major products. We also discuss the direction of future wire development.

Keywords: magnet wire, enameled wire, thermal resistance, scrape resistance

1. Introduction

Magnet wire is a generic name for the electrical wire used to convert electrical energy to magnetic energy and vice versa, and it plays an important role in wide-ranging areas in our daily lives as a core component of vehicular electrical equipment, industrial motors, home appliances, electric power equipment, and telecommunication devices. There are various types of magnet wire, including spiral-shielded wire, in which a copper or other conductor is shielded with silk, cotton, paper, thread, film, or glass; oil-based enameled wire shielded with natural resin such as drying oil; and synthetic enameled wire coated with synthetic resin varnish as an insulator, which is currently the most common type of magnet wire.

Sumitomo Electric Industries, Ltd. (Sumitomo Electric)'s magnet wire business started in 1916. The rapid progress of post-war industrialization also accelerated expansion of synthetic resin industry, resulting in the development and market introduction of various synthetic resins suitable for wire insulating shield. Since those days, Sumitomo Electric has been continuing the development of materials and products to keenly respond to the needs of our wide-ranging client industries, including home appliances and vehicles, which are ever advancing. Further, recent globalization expanded our markets beyond Japan and into China, Southeast Asia, and other overseas regions. In 1969, Sumitomo Electric established its first overseas production site of magnet wire in Thailand. Such production sites now total five thanks to steady market expansion. In recent years, Sumitomo Electric has been particularly focusing on scrape resistance and thermal resistance magnet wire, which is our forte, for in-vehicle usage (Photo 1).

This paper summarizes the history of Sumitomo Electric's magnet wire business and its product development and discusses future prospects.

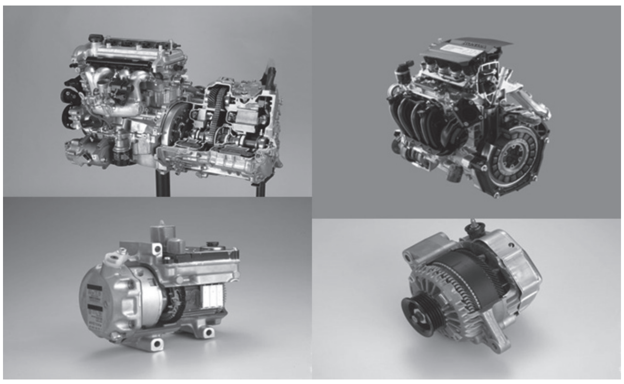

Photo 1. Products Utilizing Sumitomo Electric Magnet Wire

2. The Dawn of Sumitomo Electric Magnet Wire Business

The history of magnet wire can be divided into three major eras: the period before WWII; the post-war recovery period between the end of WWII and 1955; and the expansion period from that time to the present day. This chapter summarizes the dawn of Sumitomo Electric's magnet wire business from 1916 to around 1955.[(1)-(3)]

2-1 From inauguration of magnet wire business to post-war recovery

Sumitomo Electric has started production of enameled wire in the coated wire factory within Osaka Works, which opened in 1916 during WWI. Sumitomo Electric specifies this year as the first year of its magnet wire business (Table 1). At that time, both the number of wire types and production volume were small and the produced wires were insulated using oil-based enamel, cotton, silk, and paper. The oil-based enameled wire was a copper wire coated and baked with natural resin made of a drying oil, such as tung oil, as the insulation. Oil-based enameled wire was always further covered with cotton or paper, except when it was to be used for a small magnet coil, because enamel has low mechanical strength.

In 1943, Sumitomo Electric opened Nagoya Works. However, 70% of its factory building either collapsed or burnt down and became wasteland by the Tokai Earthquake in 1944 and an air raid early in 1945.

The oil-based enameled wire production facilities were transferred to an evacuation factory during WWII and moved to Nagoya Works immediately after the war. Efforts to recover the premises enabled Nagoya Works to resume operations in 1946.

In 1940, Sumitomo Electric's research department commenced studies on magnet wire coated with synthetic resin, with a focus on resin synthesis and production methods. Without making any major success by the end of WWII, this research was suspended in 1944; however, it made a significant contribution to the Sumitomo Electric's magnet wire business after the war. Meanwhile, in the U.S., General Electric had announced their invention of synthetic enameled wire using polyvinyl formal (PVF) in 1939. The mechanical strength of wire coated with synthetic enamel is greater than that of wire coated with oil-based enamel and the former was welcomed by countries around the world as a novel product that could be used without protective shielding. Many countries began their own research following this announcement but their research status was unknown due to the outbreak of WWII.

2-2 Commercialization of Formet wire and its expansion

Sumitomo Electric restarted its research after WWII and has particularly focused on the commercialization of polyvinyl formal enameled copper wire (hereafter, Formet wire) partly due to customer demand. Thanks to the expertise already accumulated during the two wars, our research progressed quickly. As a result, sales of Formet wire commenced in 1950 under the product name of "Formet Wire." Sumitomo Electric's exclusive technology resulted in Japan's first synthetic resin enameled wire to be domestically developed and commercialized. With its excellent

Table 1. Major Events and Procucts in Sumitomo Electric's Magnet Wire Business

FY	Major events	Product development
1897	Sumitomo Copper Rolling Works was founded (Business foundation)	
1911	Sumitomo Electric Wire & Cable Works established (Company foundation)	
1916	New Factory (now Sumitomo Electric Osaka Works) established	Started production of enamel wires
1920	Sumitomo Electric Wire & Cable Works established as a limited company (Company registration)	
1939	Company name changed to Sumitomo Electric Industries, Ltd. (Current name)	
1943	SEI Nagoya Works opened	
1945	Magnet wire production facility moved to Nagoya Works and enameled wire production commenced	
1950		Formet wire production started
1951		Glass insulated magnet wire production started
1958		Polyester wire production started
1960		Honeycomb polyurethane wire developed
1961		Fluororesin wire developed
1962		Polyester nylon wire production started
1963		Ultra-fine wire developed
1965		Polyester wire ATZ-100 developed
1967		Modified polyester wire ATZ-200 developed
1968	Sumitomo Electric Magnet Wire Division inaugurated	
1969	Our first overseas production site, Siam Electric Industries Co., Ltd (Current WIN-T) established in Thailand	
1970		Thermal resistance ATZ-300 developed
1972		Short circuit induction wire NCW developed
		Solderable 155°C-class enameled wire FEIW production started
1973	Sumitomo Electric (Singapore) Pte., Ltd. (WIN-S) established as a production site in Singapore	Solderable 155°C-class wire ATZ-400 developed
1974		Self-bonding wire for TV deflection yoke coil SSB-60 (EIW + Nylon) developed
		Thermal resistance self-bonding wire SSB-11 (ATZ-300 + epoxy) developed
1975		Self-lubricating polyester nylon wire PEW-N developed
1976		Solderable thermal resistance urethane wire SEUW developed & production started
1977		Super-fine rectangular wire developed
1978		Self-bonding wire SSB-SE (SEUW + epoxy) developed
1979		Self-bonding wire SSB-EE (PEW + epoxy) developed
		Self-lubricating thermal resistance wire HLW developed & production started
1988	Sumitomo Electric Magnet Wire (M) Sdn., Bhd. (Current WIN-M) established as a production site in Malaysia	High-speed magnet wire Ultra-fine wire UEW-H developed
1989	SPD Magnet Wire Company (Current WIN-A) established as a production site in the U.S.A.	SSB-HD & SSB-98 for deflection yoke coil developed
1992		Magnet wire for new refrigerant R134a, GLW developed
		Highly strong magnet wire UHW developed
1994	SES BATAM established as a production site in Indonesia	Gasless thermal resistance urethane wire SR-SEUW developed
1995	Sumitomo Electric (Wuxi) established in China (Current WIN-W)	
1996		Scrape resistance thermal resistance wire UTZ developed
2000	Sumitomo Electric Magnet Wire established as a production company and Wintec Wire established as a sales company	
2002	Sumitomo Electric Wintec, Inc. established and commenced sales business	
2004	Sumitomo Electric Wintec Nagoya Works (Previous Sumitomo Electric Nagoya Works) closed	
2008	WIN-A production ended; changed to a sales site.	Scrape resistance thermal resistance wire for resin impregnation HGZ developed
		Refrigerant resistance self-bonding wire SSB-41 developed
2011	WIN-S closed and merged with WIN-M	

electrical characteristics, mechanical strength, and thermal resistance, the wire contributed to the downsizing of electrical equipment. For these two reasons, the wire has significant historical value. The high reputation of the wire throughout the industry led to the rapid expansion of its production facilities and factory in Nagoya Works, which became the center for today's Sumitomo Electric's magnet wire development. In the first year of the mass production of Formet wire in 1950, the production volume was a mere two tons. By 1956, this had increased to more than 100 tons following the establishment of a new Formet wire factory. Further enhancement of the facilities pushed this figure to 320 tons by 1960. According to the paper of the Sumitomo Electric Review published in 1955, the rapid increase in demand was described as follows: "This was the period when the practical application of Formet wire and glass insulated magnet wire was established and such technical maturity attracted the market's highest demand. To quickly respond to this situation, we have newly built factories for Formet wire and glass insulated magnet wire, and organized and reinforced their production facilities in order to cope with the surge in demand while retaining high quality and high efficiency."

Through the commercial application of PVF, the major coating material for the magnet wire shifted from oil-based enamel to synthetic resin. This was also the period when the post-war development of synthetic chemistry was taking place, producing and commercializing various new resins.

3. New Product Development in the 1960s and Later

3-1 Further development of synthetic resin enameled wire

Following PVF, a variety of synthetic resins were developed. Most of the basic types of synthetic resins were released by 1970. Sumitomo Electric also continued the development of specialized synthetic resin enameled wires other than PVF wire, and developed wires insulated with polyester, solderable polyurethane, urethane-modified PVF that can withstand the R-22 refrigerant used in air conditioners, and polyamide-imide. Compared to the development of Formet wire, development of some of these wires was not industry-leading, however, Sumitomo Electric gained the skills to quickly develop applied coating materials with special functions based on fundamental coating materials, and this later led to the development of a variety of products.

3-2 Thermal resistance wire: ATZ-300

In 1968, Sumitomo Electric attempted to develop wire with a polyester-imide single coating as a part of commercialization of thermal-resistance rotary compressor for air conditioners, however this single coated wire did not satisfy the requirements. Instead, the company developed double-coated wire using the 180°C-class modified polyester-imide as the base layer and polyamide-imide as the top layer. This double-coated thermal resistance wire, ATZ-300,[4] was characterized by its multi-functionality and delivered by the combination of two coating materials. The disadvantages of the polyester-imide basecoat layer were compensated for by the polyamide-imide topcoat layer that performs better in all aspects as the protective shell. Compared to the single-coated wire described above, ATZ-300 showed better performance in thermal resistance stability, windability, refrigerant resistance, crazing resistance, and humidity-thermal resistance. The double coating of polyester-imide and polyamide-imide reduced costs while achieving high performance (Fig. 1).

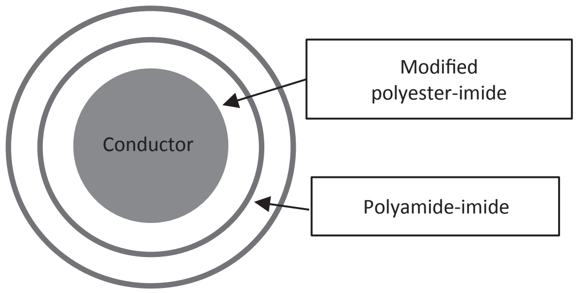

Fig. 1. Cross-section of ATZ-300

3-3 Solderable wire

Since about 1970, the downsizing of home appliances and weight reduction of vehicles and aircraft have progressed significantly. This in turn has increased demands for magnet wire to be more thermal resistance. One related issue that arose was that ordinary chemicals could not remove the coating on wires, as thermal resistance wires in general show good chemical resistance. The coating at the end of the wire always needs to be removed to use the wire. If the wire is coated with molten solder, chemicals cannot remove the coating completely, and mechanical removal requires each wire to be processed individually—a task that cannot be automated. Thus customers needed to spend extra hours to remove the end coating of the thermal resistance wire before using it. Working together with a varnish manufacturer, we developed a solderable polyester-imide resin.[5] In 1973, we developed ATZ-400, a solderable wire with a polyamide-imide topcoat and 155°C-thermal class. ATZ-400 is not currently in production due to lack of demand, however, the solderable polyester-imide developed for this wire was widely used as the undercoat of self-bonding wire for the deflection yoke coil in a cathode ray tubes in displays for PCs, whose production increased rapidly during the 1990s. The single-coated FEIW is still in production today.

3-4 Self-lubricating wires: PEW-N and HLW

The first oil shock in 1974 caused a price surge in varnish materials (1.7 times higher than pre-oil shock). This urged magnet wire customers to reduce component costs and improve work process efficiency more than ever before. As a part of efforts to respond to this situation, we commenced research on improving the lubricity of magnet wire in order to improve work efficiency for our customers, such as in winding and coil insertion. The types of wire subject to this research were polyester wires that had the highest production ratio (39%) at that time and which were cost effective to work on. Utilizing polyester nylon, which we developed in 1962, as a base, we added lubricant to the nylon 66 topcoat and managed to reduce the coefficient of static friction (μs) from 0.15 to 0.05. Production costs were minimized by reducing the thickness of the self-lubricating nylon topcoat, resulting in a high performance product for around the same cost as the conventional product. Later, when demand for self-lubricating thermalized wire increased, Sumitomo Electric developed HLW in 1986. Based on ATZ-300, HLW was a wire coated with self-lubricating film utilizing the self-lubricating technology established in the development of PEW-N. The self-lubricating wire was commonly used in the motors in hermetic compressors for refrigerators and air conditioners. The motor has to run within the compressor, where refrigerant and refrigerating machine oil are flowing together. Therefore, additional lubricant, such as paraffin, cannot be applied on the wires used in this motor. Also, such wires need to have excellent refrigerant resistance within the refrigerating machine oil in which high-temperature and high-pressure refrigerant vapor and refrigerant are fused. Our self-lubricating wire fully satisfied these requirements. However, types of refrigerant were changed due to the restrictions on chlorofluorocarbons (CFCs) after the late 1980s and we needed to select magnet wires that withstand alternative refrigerants. After a thorough assessment and verification, Sumitomo Electric's self-lubricating wires were found to also be resistant to such alternative refrigerants.[6]

3-5 Scrape resistance wires: UTZ and HGZ

As the number of devices that are required to have a high space factor*1 for downsizing and higher performance, the thermalized enameled wire used in such devices also needed to meet requirements that seemed almost "too harsh." In 1996, we developed the scrape resistance wire UTZ,[7] in which the lubricity was further improved and its scrape resistance was heightened to the maximum by closely adhering the insulation to the conductor (Fig. 2). These new developments were the first of their kind in the industry and the wire was commercialized ahead of competitors. UTZ became our representative product, making us the market leader. The wire was adopted in the world's first hybrid electric vehicle (HEV) and contributed to performance advancement and downsizing of the driving motor, the major core component of the vehicle.

Motors are generally of two types: one is impregnated and the other is non-impregnated, and the need for improved performance in the impregnating resin is high.

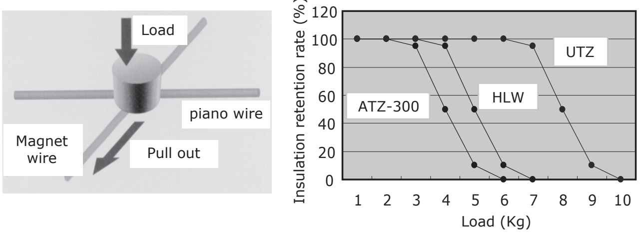

Fig. 2. Comparison of scrape resistance for thermal resistance wire

To increase the space factor of the impregnating resin, we improved UTZ's compatibility to impregnating resin to add to its excellent scrape resistance characteristics. This was achieved as the scrape resistance wire for resin impregnation, HGZ, developed in 2008.[8]

3-6 Self-bonding wire

Self-bonding wire is an enameled wire with a bonding resin coat on top of the insulation coat. After winding this wire into a coil, the coil can be heated to melt the bonding coat to fix the wound wire. The coil made with the self-bonding wire can retain its shape well, and for this reason, the wire was most commonly used for deflection yoke coils that display pictures in the cathode ray tubes used in televisions at that time. The self-bonding wire, SSB-60 (EIW + nylon), for TV deflection yoke coil was developed in 1974. The demand for high definition image displays increased in the following years, and this led to development of self-bonding wires for high definition deflection yoke coil, SSB-98 and SSB-HD, which used high-performance bonding materials.[9],[10] Later, LCD TVs became widespread and demand for the self-bonding wire for deflection yoke coils disappeared.

Self-bonding wire was also used as the means to eliminate motor impregnation. Impregnation has environmental issues as it requires long heat processing with the vaporization of solvents. To help such a situation, we developed self-bonding wires SSB-EE (PEW + epoxy) and SSB-11 (ATZ300 + epoxy) for general motor use, as well as the refrigerant-resistant self-bonding wire, SSB 41, for special motors that run while immersed in a mixture of refrigerant and refrigerating machine oil.[11]

4. Future Prospects

Compared with UTZ which was adopted in the driving motors of the first HEVs, an amide-imide wire (AIW) has more stable thermal resistance and better anti-degradation capabilities in wire treatment. Thus, AIW has been used as a magnet wire for high voltage motors, such as for the newer HEV driving motors. Customer demand for further improved thermal durability, anti-degradation, and insulation (improvement of PDIV*2) has increased greatly in recent years. To respond to this demand, we have recently developed and commercialized our polyimide wire (PIW), which has better capabilities than AIW, as the magnet wire for HEV usage.

Table 2 compares the characteristics of AIW and PIW. PIW shows better performance in all aspects of thermal resistance, ultimate elongation of coating, insulation quality (permittivity*3); however, PIW is more expensive than AIW. To reduce PIW costs, we refined a method of synthesizing varnish material resin and established the technology to generate a suitable resin at a reasonable cost. Through this technology, we could reduce the PIW sales price and release a magnet coil with excellent price competitiveness.

Compared to round wire, coating distribution on a rectangular wire tends to become uneven. The thickness of the coating formed by baking is always less at the corners of rectangular wire. To satisfy insulation requirements, performance must be guaranteed with the dielectric

Table 2. Comparison of Characteristics Between Amid-Imide Wire (AIW) and Polyimide Wire (PIW)

	Amid-imide wire (AIW)	Polyimide wire (PIW)
Thermal resistance class	220°C	240°C
Thermal durability	220°C×500 h_NG	280°C×2000 h_OK
Ultimate elongation of film	~ 45%	~ 80%
Permittivity	4.3	3
Water absorption	4.5%	3.0%
Glass transition temperature	280°C	350°C
Elastic modulus at 400°C	30 MPa	1000 MPa

strength voltage at the thinnest point of the coating. Uneven coating could produce unnecessarily thick areas in order to ensure this performance guarantee. We have developed a baking method to eliminate such uneven coating and achieved production of uniform coats (Fig. 3). This enables us to coat the wire evenly with the minimum required amount and at the same time reduce costs.

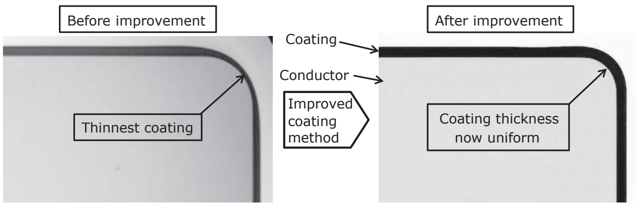

Fig. 3. Improvement of Coating Material Distribution

Figure 4 summarizes the development roadmap of magnet wire for in-vehicle usage. On top of price reduction, we expect that the functionality required for the magnet wire to improve motor performance would be high insulation and high durability against the necessary wire processing. We believe that it is indispensable to develop a

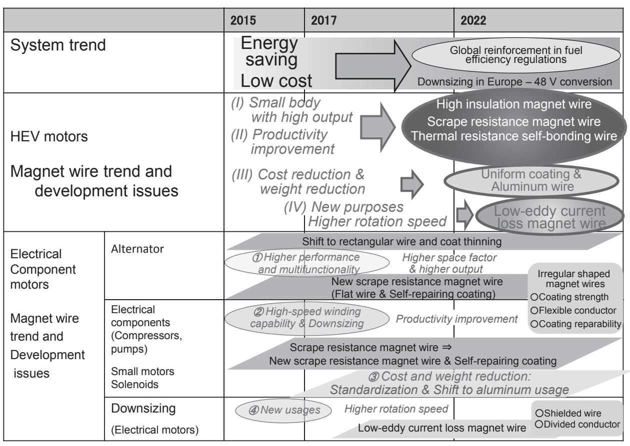

Fig. 4. Development Roadmap of Magnet Wire for Vehicle Electrical Component Use

product that can achieve high functionality and a low price at the same time.

Sumitomo Electric continues to conduct research into the next generation of magnet wires. One example of such research is a type of magnet wire that has even higher insulation performance than PIW. To achieve high PDIV it is necessary to reduce the electrical permittivity of the coating. We developed a porous coating structure in order to reduce the permittivity of the entire coating. Introducing small holes into the PI coating creates scattered air spaces where the permittivity is almost 1. Uniformly reduced permittivity was achieved throughout the coating by evenly distributing the holes. PI's standard permittivity is 3.0, but by adjusting the air space to be 50% of the PI base layer we confirmed that this was reduced to 1.7 in our porous coating.

5. Conclusion

In this paper we discussed the history of magnet wire development in Sumitomo Electric along with some major products, and also mentioned the direction of future product development. Sumitomo Electric has been offering a range of magnet wires that respond to the requests of customers in different fields, and we will continue to pursue this into the future. The vehicle industry is an important area where magnet wire demand is expected to continue to rise. Sumitomo Electric will further advance it to development of multi-functional high-performance magnet wire and offer them throughout the market.

• Wintec, Wintec Wire, ATZ, SSB, SEUW, HLW, GLW, UHW, and UTZ are trademarks or registered trademarks of Sumitomo Electric Wintec, Inc.

Technical Terms

∗1 Space factor: Space factor refers to the ratio of the cross-sectional area of magnet wire conductor to the cross-sectional area of the slot where the magnet wire is housed within the motor core. The bigger the factor, the larger the motor output.

∗2 PDIV: Abbreviation for partial discharge inception voltage. Also known as the corona starting voltage.

∗3 Permittivity: The measurement of polarization strength when placing a conductor in a magnetic field. A low permittivity causes a high PDIV because electrical discharge is less likely to occur.

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