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Development of Nippon Steel & Sumitomo Metal Corporation's Seamless Mechanical Tubing

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Abstract

Development of NSSMC's seamless mechanical tubing has been largely encouraged by the growth of the automobile, the construction machine and the industrial equipment industries. Since 1985, the customer's requirements such as high strength, high toughness and the light-weighting have improved with the times NSSMC has been developing new products in response to the customer's demand, and providing the products to the market. The tubing for bearings, airbag inflators and the fuel injection tubes for diesel engines are the typical achievements, and this enables NSSMC to establish the steadfast status in the industries. This paper describes the development and the main products of the NSSMC's seamless mechanical tubing.

1. Introduction

The manufacture of seamless mechanical tubing at Nippon Steel & Sumitomo Metal Corporation dates back to 1935 when Tokyo Works of the former Nippon Steel Corporation started centrifugal cast steel pipe production, and even further back to 1917 when the former Sumitomo Metal Industries began test-manufacturing steel pipes for aircraft and periscopes. In prewar Japan, the two companies manufactured hot-formed pipes and tubes in small lots for special purposes, including the munitions industry. After the war, their pipes and tubes became mass production items. Soon after the war, Japan's industry, particularly the automotive industry, began developing rapidly, leading to demand for increased production of higher-grade steel pipes and tubes. The development of new tubular products and expanded demand for them were most conspicuous in the motor vehicle industry.

As times changed, the needs of the automotive industry became more sophisticated. Specifically, the industry has continually demanded new tubular products that are higher in strength and toughness, lighter in weight, and superior in cleanliness, formability, weldability, etc. To meet those needs, Nippon Steel & Sumitomo Metal has proactively introduced new and advanced equipment and developed new products. For example, in 1989 the company started the production of steel tubes for bearings, employing the world's first continuous spheroidizing heat treatment furnace, and in 1993 it began the mass production of steel tubes for airbag inflators that are required to have high strength and high toughness. Thus, the company has consolidated its position in the industry while responding to ever-diversifying customer needs.

Actually, the expansion of demand for seamless mechanical tubing and the development of new products owe much to advances in automobiles, construction equipment and industrial machinery. In this report, the author and collaborators review the main products of seamless mechanical tubing developed by the company in and after 1985, when demand for seamless mechanical tubing expanded markedly.

2. Development of Mechanical Tubing for Automobiles

2.1 Development of high-grade mechanical tubing (1985-1992)

Following the Plaza Accord of 1985, the Japanese economy experienced a sharp appreciation of the yen. Then, under the influence of the bubble economy, the automotive industry enjoyed increased demand for high-end cars. Accordingly, demand for higher-performance vehicles expanded markedly. At the same time, steel pipes and tubes for automobiles were required to have higher strength and toughness, and lighter weight. To fully meet those needs, the company proactively upgraded its production facilities.

(1) Input shafts and steering rack tubes

Input shafts and steering rack tubes are among the products that were formerly made from solid round bars, but now are made hol-

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low to reduce their weight. In addition to reducing the weight of those automotive parts, another purpose of product development was to omit a manufacturing process on the customer side. Since Input shafts and steering rack tubes are both small-diameter, thick-walled parts (the ratio of wall thickness to outside diameter is about 30%), wall thickness accuracy for the hot-rolled pipe blank was formerly key to their mass production. Thanks mainly to rolling control technology using a process computer, and to the optimization of rolling conditions based on rolling simulations using the finite element method,[1-4] pipe blank dimensional accuracy has been improved to the extent that manufacturing hollow input shafts and steering rack tubes is now possible (**Figs. 1 and 2**).

(2) Ball cages

With growing environmental consciousness, the tubing for ball cages of constant-velocity universal joints was also required to be smaller in size, lighter in weight, and higher in efficiency. Therefore, in 1992 the company teamed up with customers to launch the joint development of high-strength, thin-walled tubing. Due to feature of final products, the tubing is required to have good torsional properties, hardenability, and formability, all of which have been achieved through optimum composition design. The company started mass production of this type of tubing in 1998. By 2005, ball cages of the new type of tubing largely replaced those of conventional steel pipe, contributing much to the reduction of size and weight and the enhancement of ball cage efficiency (**Fig. 3**).

(3) Bearing steel tubes

Bearing steels must be extremely hard and have excellent fatigue strength, dimensional accuracy, good wear resistance, machinability, etc. In Japan, therefore, high-carbon chromium bearing steels (JIS SUJ 2) are generally used. With advances in steelmaking technology, the fatigue life of bearing steels has been prolonged markedly. On another front, in the 1980s demand for clean bearing steels became stronger than ever before. Against this background, Nippon Steel & Sumitomo Metal developed its own steelmaking, pipe forming and heat treatment technologies, and in this way established an advanced system for manufacturing steel tubing for bearings. This system has two salient characteristics. One is an integrated process for blast furnace-converter-vacuum degassing-continuous casting, which permits the manufacture of high-cleanliness steel with only extremely small amounts of impurities and nonmetallic inclusions.[5-7] The other is the uniform dispersion of carbides by cyclic heat treatment,[8-10] in addition to the development, and introduction in 1989, of the continuous bright annealing furnace that allows for the control of carburization/decarburization and the application of conventional slow cooling for the spheroidizing heat treatment of bearing steels. As a result, it became possible to mass-produce high-grade tubing for bearings having a long fatigue life and excellent machinability. Even today, the tubing for bearings is one of the company's leading seamless mechanical tubing products (**Fig. 4**).

2.2 Development of high-end mechanical tubing (1993-2013)

In the wake of the collapse of the bubble economy, domestic sales of automobiles dropped sharply. Meanwhile, aggravation of such environmental problems as global warming and CO_2 emissions called for greater environmental protection and motor vehicle fuel efficiency. Other demands focused on automobile safety. This resulted in the need for diverse types of mechanical tubing. Thus, there is now an ever-growing need to develop high-end mechanical tubing products that are not only high in strength and toughness but also compact in size, light in weight, and superior in cleanliness and dimensional accuracy, etc.

(1) Tubing for airbag inflators

Since the 1990s, laws and regulations governing automobile safety standards have become well established, mainly in the United States and Europe. This has led to a dramatic increase in the number of vehicles equipped with airbags. Airbags can largely be divided into two types — the hybrid type that inflates the bag with stored compressed gas, and the pyrochemical type that inflates the bag with

Fig. 1 Input shaft

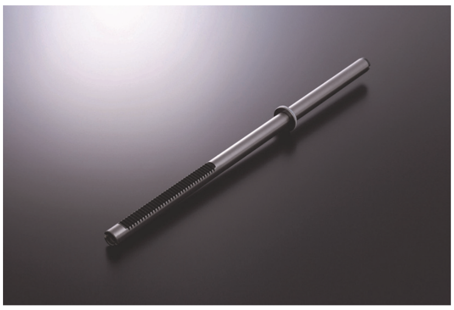

Fig. 2 Steering rack tube

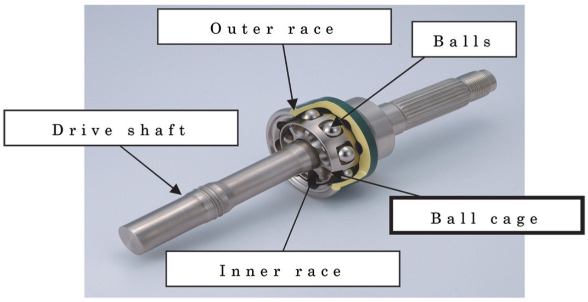

Fig. 3 Constant velocity universal joint

Fig. 4 Water pump bearings

the combustion gas of an explosive. Side and curtain airbags are installed relatively near to passenger seats and filled with a high-pressure gas because they are required to activate immediately in the event of a crash. This is why the hybrid type with a seamless tubing inflator is mainly used for them. Nippon Steel & Sumitomo Metal started, ahead of other manufacturers, the development of tubing for airbags, which are now one important safety-related automobile part. Employing its cold drawing and heat treatment technologies, the company successfully commercialized the world's first seamless tubing for airbag inflators in 1993.

Performance requirements for airbags include strength, toughness, formability, weldability and dimensional accuracy. When tubing for airbags was first marketed, steel having a tensile strength of 800 MPa was mainly used. However, with growing demand for lighter airbags and higher gas pressures, customer requirements for higher-strength materials continued to increase. The company has therefore developed one new product after another — 950 MPa steel in 1999, 1,050 MPa steel in 2007, and 1,100 MPa steel in 2012 (**Figs. 5 and 6**).

(2) Tubes for diesel engine fuel injection pipes

With the aggravation of environmental problems, such as the global warming, and the aggravation also of energy problems, such as soaring crude oil prices, the development of hybrid, electric, and fuel-cell vehicles has become more prevalent. In addition, conventional gasoline- and diesel-engine cars are increasingly being required to achieve better fuel efficiency, lighter vehicle weight, and cleaner exhaust gases. The diesel engine has been targeted for the problem of producing black exhaust, although it emits less CO_2 than the gasoline engine. In view of diesel engine pollution and the harmful effect of pollution on the human body, many countries are imposing increasingly stringent environmental regulations, and this is increasing the urgency for making diesel engine exhaust fumes cleaner.

Fig. 5 Side airbag inflator

Fig. 6 Curtain airbag inflator

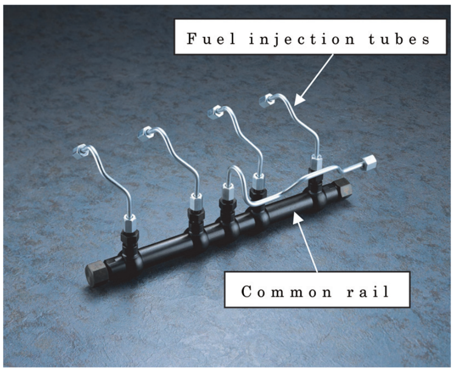

Fig. 7 Fuel injection tube for common rail type

As one measure, efforts were made to reduce black exhaust gas emissions by raising the pressure of diesel fuel injections into the combustion chamber. Fuel injection tube performance requirements are high strength, and high fatigue strength. With that in mind, the company worked with a customer on the joint development of a new type of fuel injection tube. Utilizing the company's technologies for controlling nonmetallic inclusions, and for developing rolling small-diameter tubes with high dimensional accuracy, and while also implementing optimum composition design, in 2010 the company and customer jointly developed a fuel injection tube that permits an injection pressure of 200 MPa. This was a world first. The company is still developing new steel materials capable of withstanding higher pressures, in response to environmental regulations that are becoming increasingly stringent (**Fig. 7**).

3. Development of Mechanical Tubes for Construction Equipment and Industrial Machinery (1985 to the Present)

(1) Mechanical tubes for construction equipment

In the construction equipment field, as in the automotive sector, demand continues to grow for equipment that is higher in strength, as well as lighter in weight to help improve fuel efficiency. To meet this demand, the company developed the new steel products "WELTEN" and "SUMISTRONG." By the end of the 1970s, it had lined up a variety of high-performance steel products that exhibited up to 800 MPa in tensile strength.

In recent years, with increases in the size of construction cranes, there has been increased demand for stronger, lighter steel tubes for crane booms (to reduce the weight of the counterweight fitted to the crane body). So in 2005 the company started tackling the development of "WELTEN-ST," a low-carbon, chromium-free steel featuring both high strength and good weld crack resistance. By introducing a new composition design, and a new manufacturing process (for controlling hot working) that eliminates the need for the formerly indispensable quenching and tempering process, the company ensured speedy, just-in-time delivery through process streamlining. In addition, by eliminating the need to preheat the steel to prevent weld cracks, the company helps the customer increase automation, thereby reducing welding work. More recently, the company has added high-strength steel pipes of 1,000 MPa class to its WELTEN and SUMISTRONG series, with the aim of expanding orders for them.

In addition, in response to diversified customer needs, the company offers various types of high-strength steel products, such as steel tubes for hydraulic shovel cylinders and crawler belt bushings (**Figs. 8, 9, 10**).

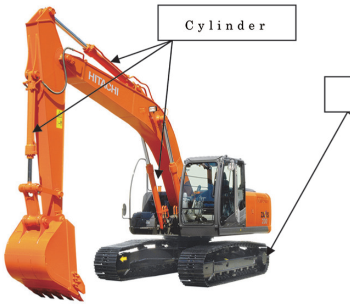

Fig. 8 Hydraulic shovel

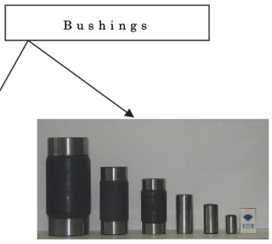

Fig. 9 Bushings

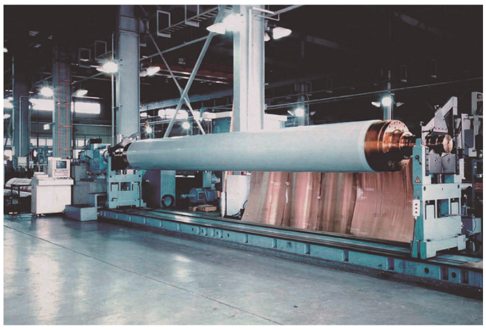

Fig. 11 Roll for printing

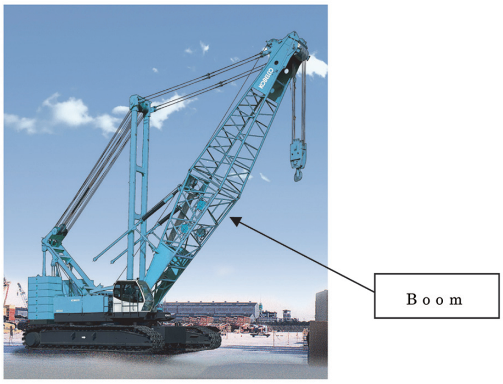

Fig. 10 Crawler crane

(2) Steel pipes and tubes for industrial machinery and buildings

A typical example of a seamless mechanical tubing application in industrial machinery is the printing roll for a rotary printing press, used to mass-print newspapers, handbills, pamphlets, etc. The company's printing rolls have been on the market since the mid-1980s, and in recent years have been widely used in gravure printing presses for printing food packaging. A high-cleanliness steel tube is used for printing rolls, since even the slightest surface flaw caused during surface grinding is not permitted (**Fig. 11**).

4. Conclusion

Quickly and accurately understanding contemporary customer needs, Nippon Steel and Sumitomo Metal has continually come up with highly competitive seamless mechanical tubes, responding in a timely fashion.

Although customer needs will become increasingly diversified in the future, one can assume that the basic performance required of all seamless mechanical tubing — high strength, high toughness, compact size, thin wall — will remain the same for some time.

To create new value for every customer, and to accelerate the differentiation from the competitors, it is considered important not only to respond accurately to the above-mentioned increasingly stringent basic performance requirements, but also to minimize non-metallic inclusions and surface defects, to develop products with new value added (formability, weldability, etc.), and to continue refining existing and new manufacturing technologies.

References

1) Yamada, T.: Plasticity and Working. 34 (384), 55 (1993)
2) Yamada, T., Yamada, M., Matsukura, S.: Plasticity and Working. 34 (392), 1022 (1993)
3) Yamada, M., Yamada, T., Kosakada, K., Okada, T.: Plasticity and Working. 34 (394), 1270 (1993)
4) Yamada, T., Yamada, M., Matsukura, S.: Plasticity and Working. 34 (395), 1326 (1993)
5) Morimoto, S., Kishida, T., Kawami, A., Hashimoto, K., Fujioka, Y., Tanaka, M.: Tetsu-to-Hagané. 72, S533 (1986)
6) Morimoto, S., Sakai, K., Nakayama, T., Fujioka, Y.: Tetsu-to-Hagané. 72, S1366 (1986)
7) Morimoto, S., Fujioka, Y., Yamaguchi, Y., Yamada, N.: CAMP-ISIJ. 3, 1863 (1990)
8) Okada, Y., Fujioka, Y.: CAMP-ISIJ. 5, 1955 (1992)
9) Okada, Y., Morikawa, T., Fujioka, Y., Tanimoto, S.: CAMP-ISIJ. 5, 1956 (1992)
10) Okada, Y.: Sumitomo Metals. 45 (1), 1 (1993)

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