Technologies Continuously Refined Together with Customers

Through a continuous cycle of material creation that is ideally suited to the sophisticated demands and challenges of its customers and the perfection of these materials to a level that can be provided to its plants for mass production, Proterial has developed a succession of unique materials that boats high functionality and quality which its has then deployed to new applications and market domains. Using the example of CVT belt materials, we will introduce our material structural and compositional control technologies that are pioneering the future of the Company. Specifically, we will look at how we developed CVT belt materials in the specialty steel business, and how we went on to develop aircraft-related materials based on this technology.

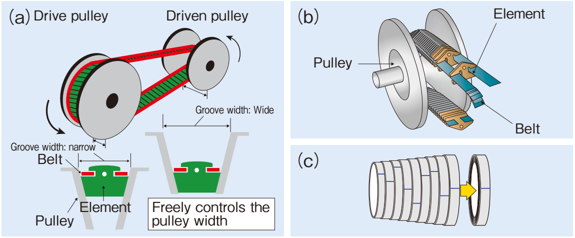
1 Metal Structural and Compositional Control Technologies and CVT Belt Materials

When conceiving of new products and businesses, the metal structural and compositional control technologies that we have built up over the years serve as a source of value creation. Relying on thermal treatment and additive element optimization, these technologies control the microstructures that determine the toughness, wear resistance, heat resistance, workability, and other characteristics of metals. By enhancing these structural and compositional control technologies, we are able to provide metals with a variety of characteristics, even when their chemical composition is the same. Moreover, we have provided metals that meet the demands of our customers by refining these technologies.

As a specialty steel product, CVT belt materials also serve as an example of a component material that we developed by leveraging our structural and compositional control technologies. CVT belt materials are designed for the continuously variable transmission (CVT) used in automobile engines, for which we currently boast the world's top share (Proterial estimate). CVT belts are made by layering about ten flat belts of metal just seven to eight millimeters wide, and securely fabricating these belts into continuous strips. CVT belts thereby function to convey motive power from the engine to the tires, and to govern gear shifting and other transmission functions when driving. Because CVT convey motive force through a belt instead of a gear, they eliminate shock when shifting and enable continuous shifting that matches the engine revolutions required for high combustion efficiency. For this reason, the demand for CVT has also expanded as automobile manufacturers have pursued greater fuel efficiency.

The CVT belt also continuously rotates while the automobile is in motion, so the metal from which they are made repeatedly undergoes bending and stretching under a state of constant load. The belt will therefore tear if there is even the tiniest of defects, which is why CVT belts require a high fatigue strength that can withstand a travel distance of 200,000 kilometers, or more than 10 million rotations, to meet the usage environment of automobiles. Possessing the world's highest level of fatigue strength by leveraging the metal structural and compositional control technologies that it has accumulated to date, and by continuing to refine these technologies together with its customers, Proterial has enabled the mass-production of CVT belt materials. As a result, we have contributed significantly to higher performance transmissions with improved reliability, and to greater fuel efficiency for automobiles.

CVT Mechanism and Structure



(a) CVT Mechanism (b) CVT Metal Belt Structure (c) Ring Set (belt) Structure

CVT Belt Material

Maraging steel belt materials developed for the continuously variable transmission (CVT), which is a major contributor to a fuel-efficient engine. Based on metallographic innovations, we have developed thin cold-rolled materials with world-class fatigue strength that contribute to upgraded transmission performance and increased reliability.

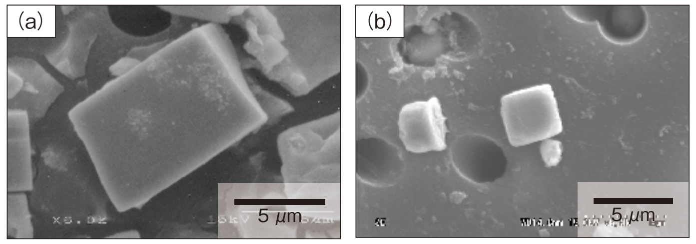
2 From CVT Belt Material Development to Mass-production

Since the 1990s, we have advanced the development of technologies designed to constrain the growth of nitrides contained in metals (TiN) using our structural and compositional control technologies for the energy domain. Meanwhile, in the automobile domain, we have built collaborative relationships with Japanese automobile manufacturers through the development of highly complex specialty materials used under harsh environments as part of an effort that has primarily focused on forging materials for engine valves. The relationships of trust we have fostered with our customers have also served as the motivation for why our customers choose us as their development partner when conceiving new products. The development of CVT belt materials was similarly triggered when a Japanese automobile manufacturer who recognized our materials development capabilities approached us about whether we could engineer a CVT belt material with a refined TiN grain suited to the usage environment of automobiles.

In general, when a component undergoes fatigue fracturing, the fractures often begin from the surface along which a material has been cut. In order to achieve a fatigue life that can withstand the more than 10 million rotations corresponding to the usage environment of automobiles, however, the material surface must be free from defects. Specifically, the inside of the metal must also be devoid of contaminants to the greatest extent possible. Materials with a high nitrogen content will form larger TiN grains, which will in turn shorten the fatigue life of the metal. For this reason, we had to address the extremely challenging demand to constrain the size of the grains to less than 10 microns, about half the conventional grain size.

In fact, we required two and a half to three years to achieve the customer's required standard after receiving their development request. At the outset of mass-production, the acceptance rate for the TiN dimensional standard was only about 10%, yet we continued to develop the technology further in order to improve the yield of the production process. As we did so, we came face-to-face with a new challenge, namely that different samples would demonstrate varying TiN grain sizes and unstable quality, even at the same level of nitrogen content. Therefore, we patiently tracked, evaluated, and verified the production process, and eventually discovered that the TiN grain size correlated to the magnesium content of the material. Having identified the technological background, we moved on to analyze the mechanisms and proceeded with quality control that actively utilized magnesium. This effort improved yield and opened the path to stable mass-production. Ultimately, this special process for adding and controlling additive elements established a mass-production system with a TiN dimensional standard acceptance rate of nearly 100%.

As a product that helps increase the fuel efficiency of automobiles, CVT belt materials were later adopted by other Japanese automobile manufacturers and overseas automobile manufacturers alike. During this period, we also addressed new demands from our customers, including detoxifying the impurities in the metals, based on the test results and knowledge we had acquired through our past technological developments. CVT belt materials thus came to be equipped on a growing number of vehicle models starting in the 2000s, and became a mainstay product that has driven our sales upward since 2010.



(a) TiN Generated by Conventional Technologies (b) TiN Generated by the Technology We Developed

3 Technological Deployment to the Aircraft Domain

The TiN grain refinement technology we acquired through the development of CVT belt materials expanded in new ways. This included application as an aircraft-related material.

As our next pillar of business, Proterial is now focused on developing aircraft-related materials indicating an outlook for market expansion over the medium- to long-term. We have therefore made large-scale investments at the Yasugi Works as the Company's main manufacturing plant, including a 24-ton vacuum induction melting furnace, which is also used for producing CVT belt materials, a 10,000-ton free forging press, and a high-speed radial forging machine. We established Japan Aeroforge, Ltd. (Kurashiki, Okayama Prefecture), with Kobe Steel, Ltd., and others in 2011, investing in a 50,000-ton hydraulic forging press–one of the largest in the world. In addition, Hitachi Metals MMC Superalloy, Ltd., which has an extensive track record and technological capabilities in aircraft-related materials, increased its product competitiveness by newly installing an 840-ton ring rolling mill and a large heat treatment furnace. In October 2017, we included Hitachi Metals MMC Superalloy in the Company's scope of consolidation as a wholly-owned subsidiary. As we made progress in these efforts, we received a request to develop a material for aircraft jet engine shafts in a way that applied the technologies for automobile CVT belt materials.

Although the performance required of aircraft-related materials is vastly different from that of automobiles, we achieved the stable control of fatigue strength for different requirements using control technologies perfected through our technological developments for automobiles.

In this way, one major feature of our structural and compositional control technologies is their ability to create different characteristics even for the same material. Proterial has enabled technological development for a broad range of manufacturers in the automobile market area by continuously refining the ingenuity of these technologies. At the same time, we have successfully deployed products at a relatively early stage beyond the domain of automobiles in the aircraft market area. Leveraging our structural and compositional control technologies we will continue to expand the scope of available materials, enhance technologies, and maximize the potential possessed by materials, thereby providing ideal materials that contribute to the solutions for our customers' challenges.

10,000-ton Free Forging Press

High-speed Radial Forging Machine

Yasugi Works