# Production Technology of Wire Rod for High Tensile Strength Steel Cord

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*The wire rod for steel cord is designed for high tensile strength. The steel cord is typically used to reduce tire weight. For several years, such steel cord has also been used as saw wire to cut silicon ingots. The saw wire is more highly tensile and has a smaller diameter. Therefore, an appropriate wire rod is required for manufacturing such saw wire. This report describes the technology to control non-metallic inclusions and the wire rod with superior drawingability needed for manufacturing the high strength wire used for steel cord and saw wire.*

## Introduction

Steel cord, with its excellent strength and resilience, is used in various industrial applications such as reinforcing materials for tires and conveyor belts.

The steel cord used for automobile tire reinforcement is a strand of fine wires of ultrafine drawn steel, called filaments. The downside of steel cord is its specific strength, lower than that of other reinforcing materials consisting of chemical fibers such as rayon, nylon and polyester; this is a downside that increases the weight of tires. On the other hand, steel cord has the advantages of a high modulus of rigidity, as well as excellent thermal conductivity, which prolongs the life of tires significantly and provides automobiles with superior traveling performance and driving stability.

With the proliferation of automobiles in newly developing countries, the use of steel cord is expected to increase dramatically. To meet the market needs for lighter tires, improved fuel economy and a simplified manufacturing process, there is a demand for steel cord that can be produced in larger quantities and with even higher strength.

Meanwhile, the market for solar energy generation has been rapidly growing in the last several years, since it emits no $CO_2$ during power generation and is in accord with the global effort to reduce the environmental burden. The silicon wafers used for solar panels are sliced from silicon ingots using saw wires (**Fig. 1**). To improve the yield of the material to be sliced, a saw wire must have a fine diameter. A sliced wafer, on the other hand, is required to have a cut surface with strain suppressed in order to achieve high efficiency in power generation. As a means for suppressing the strain on the cut surface, it is effective to increase the strength of the saw wires. Here again, high strength wires are demanded, as in the case of steel cord.

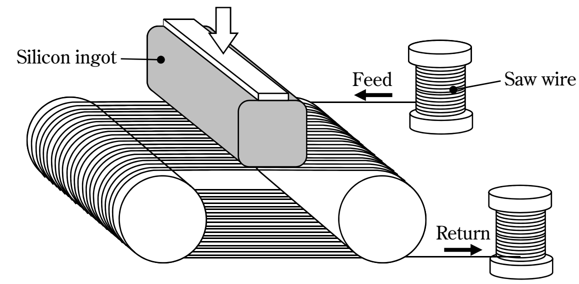


**Fig. 1** Schematic of cutting of silicon ingot

This paper describes some approaches taken to reduce the diameter of steel cord and to simplify the production process. Also described is the projected future of the wire rods used for steel cord.

## 1. Qualities required of steel cord

**Table 1** shows typical chemical compositions of wire rods produced by Kobe Steel for steel cords. **Fig. 2** shows the trend toward increasing the strength of steel cord [1]. The tensile strength of a filament with a diameter of 0.20mm was 2,800MPa in the 1970s, 3,300MPa in the 1980s, and reached a high-strength of 3,600MPa in the early 1990s and 4,000MPa in the late 1990s [2, 3]. Steel cord strengthened by wire drawing

**Table 1** Chemical compositions of wire rod for steel cord

(mass%)

| Steel grade | C | Si | Mn | P | S | Cr |
|---|---|---|---|---|---|---|
| KSC72 | 0.70-0.75 | 0.15-0.30 | 0.40-0.60 | ≦0.020 | ≦0.020 | ≦0.05 |
| KSC82 | 0.80-0.85 | 0.15-0.30 | 0.40-0.60 | ≦0.020 | ≦0.020 | ≦0.05 |
| KSC90 | 0.88-0.93 | 0.15-0.30 | 0.40-0.60 | ≦0.020 | ≦0.020 | ≦0.05 |
| KSC92-E | 0.90-0.95 | 0.10-0.25 | 0.30-0.50 | ≦0.020 | ≦0.020 | 0.10-0.30 |
| KSC105-E | 1.02-1.07 | 0.15-0.30 | 0.20-0.40 | ≦0.020 | ≦0.020 | 0.10-0.30 |

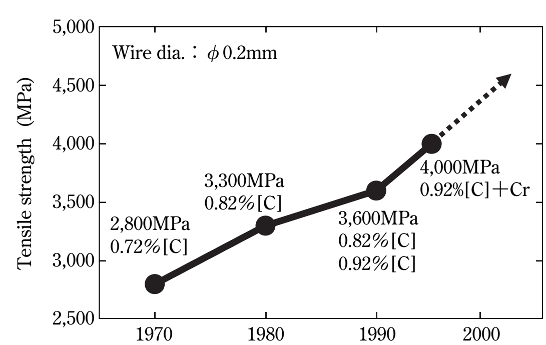


**Fig. 2** Trend of high tensile strength of tire cord

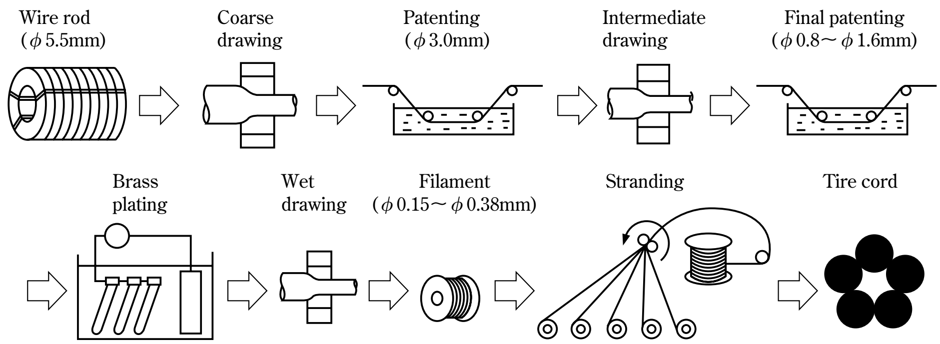


**Fig. 3** Manufacturing process of tire cord[2)]

follows the microstructure of pearlitic steel which has a layered structure of ferrite and cementite. Steel cord has the highest strength among the mass produced materials in practical use. To make it stronger, the carbon content in the wire rod has been increased from 0.7% C (hypoeutectoid steel) to 0.8%C (eutectoid steel) and then to 0.9%C (hypereutectoid steel).

**Fig. 3** depicts a typical manufacturing process of steel cord used for tire reinforcement[2)].

A hot-rolled wire rod with a diameter of φ5.5mm is processed according to the steps of dry wire drawing, intermediate patenting, brass plating and wet wire drawing, up to which point both the steel cord and saw wire are produced by almost the same process. The filaments that constitute steel cord have extremely small diameters of φ0.15 - φ0.38mm and are subjected to strong torsional stress during the wire-stranding step after the wet wire drawing. This can cause the filament to break, decrease productivity and degrade the filament quality. Therefore, stringent quality is required throughout the entire length of each filament.

A saw wire, on the other hand, is used as a solid filament and does not include a stranding step in its manufacturing process. The wire has an ultrafine diameter of φ0.08 - φ0.20mm to improve the yield of the material to be cut. In addition, the wire is repeatedly subjected to bending stress and tensile stress during cutting. Thus the tensile strength of a saw wire can reach as high as 4,000MPa (**Fig. 4**).

**Fig. 5** shows the relationship between the tensile strength of a filament for steel cord and the wire breakage frequency (index) during the stranding step, showing a rapid increase in the breakage frequency as the strength increases.[3)] The cause of the breakage, attributable to the wire rod, includes surface scratches, centerline segregation and inclusions. In particular, an inclusion as small as several tens of microns can not only become the starting point for wire breakage (**Fig. 6**), but also affect the fatigue characteristics[4)]. Thus, the cleanness of the steel definitely affects the quality of wire rods for steel cord, and non-metallic inclusions must be further reduced to prevent the wire breakage associated with increased strength.

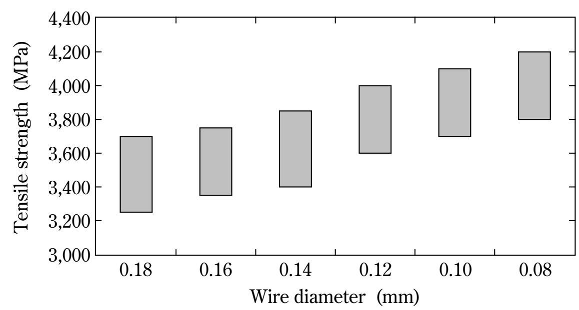


**Fig. 4** Tensile strength of saw wire

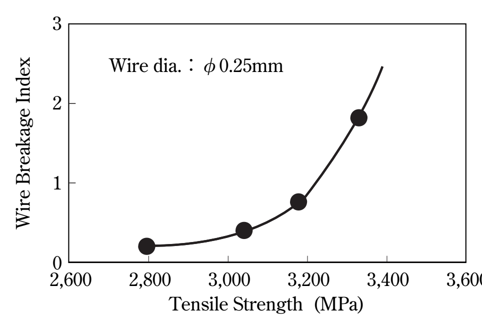


**Fig. 5** Relationship between tensile strength of filament and wire breakage index during stranding process

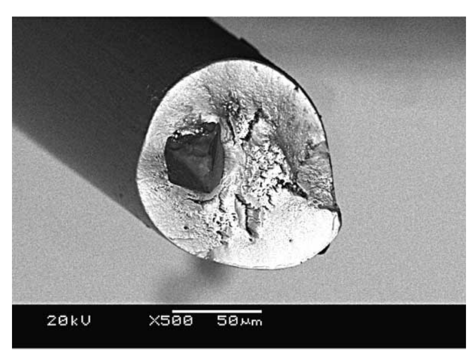


**Fig. 6** Fracture surface of steel cord

## 2. Challenge to attain zero-breakage

An inclusion that can cause wire breakage mainly consists of hard alumina, in particular, corundum ($Al_2O_3$) and spinel ($MgO \cdot Al_2O_3$), which are unlikely to elongate and likely to fracture during hot rolling and cold working[5)-7)].

Alumina can either crystallize out from molten steel, or originate from refractories. To avoid this, various measures have been implemented, including the prevention of Al from mixing into the molten steel, modification of the slag refining method and improvement of refractories.

(1) Prevention of Al adulteration

The concentration of dissolved Al in molten steel in equilibrium with a target composition is as low as several ppm. Therefore, the adulteration of Al, e.g., from alloy iron, must be controlled or restricted. Kobe Steel not only uses alloys with restricted Al concentration, but also has established a technology for suppressing Al in molten steel to a very low concentration by using a slag composition controlling technology during slag refining, as described later.

(2) Slag refining

Kimura et al. studied the fracture behavior of alumina, zirconia, zircon and silica, all of which are hard and have high melting points, during hot rolling and cold wire drawing[9)]. The micrographs in **Fig. 7** show the fracture behaviors of alumina and silica in hot rolled wire rods ($\phi$5.5mm) and in the subsequent cold drawn wires[9)]. No significant difference appears in the fracture behavior of the hot rolled materials; however, in the cold drawn wire, silica, having lower compressive strength, is fractured into smaller pieces. Inclusions that are crystallized out from molten steel, or are adulterated from refractories, should be modified into glassy compositions with a lower melting point such that they can be fractured more easily.

Inclusions in wire rods for steel cord are roughly classified into a $CaO$-$SiO_2$-$Al_2O_3$ type having its origin in slag and a $MnO$-$SiO_2$-$Al_2O_3$ type having its origin in deoxidation products. **Fig. 8** shows the phase diagrams of the $CaO$-$SiO_2$-$Al_2O_3$ and $MnO$-$SiO_2$-$Al_2O_3$ systems. In both systems, the composition range in which the melting point becomes low enough for the compound to elongate during hot rolling, and thus become harmless, lies in the vicinity of the eutectic line between anorthite and pseudowollastonite and in the area surrounding the primary phase of spessatite. Kobe Steel has succeeded in preventing hard alumina from being crystalized out and in rendering the inclusions harmless by establishing a production technology for accurately controlling slag so that it meets a target composition during slag refining.

(3) Improvement of refractories

Refractories are indispensable for treating molten steel at high temperatures. However, refractories can cause wire breakage. Kobe Steel has established a technology for using refractories as materials for receiving molten steel so that the molten steel is maintained at maximum cleanness while retaining their strength and corrosion resistance.

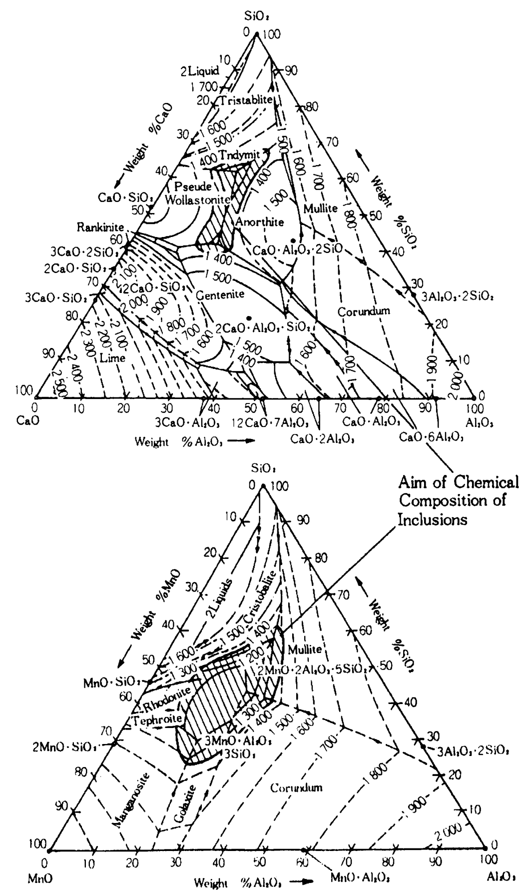

**Fig. 8** Aim of chemical compositions of inclusions

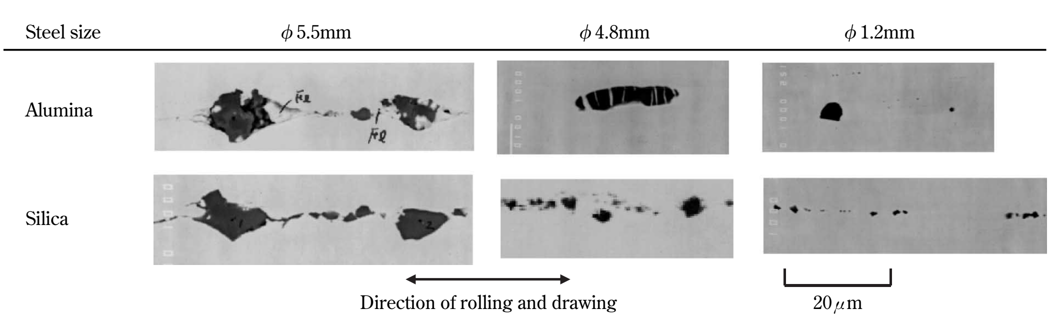

**Fig. 7** Typical examples of change in shape of oxide inclusions appeared on longitudinal section of steel wire during drawing[9)]

## 3. High drawability - Development of new product

As described above, there is an increasing demand for stronger steel cord. Research and development in pursuit of the ultimate high strength are being done on steel cord with strength exceeding 4,000MPa.

On the other hand, for the purpose of reducing the production costs incurred by cord manufacturers, new methods are being developed for direct drawing and for improving the life of dies. Direct drawing does away with the intermediate patenting that exists in the primary wire drawing of conventional materials.

Kobe Steel has been pursuing wire rods with higher strength as well as with excellent drawability, which enables direct drawing and improves the life of dies.

An index for evaluating the drawability of a wire rod is the reduction of the area of the wire rod, in which a higher reduction of area is more suitable for wire drawing. It is also indispensable to decrease the tensile strength of wire rod by increasing the interval distance of lamellar pearlite, which enlarges the critical zone for wire drawing and increases the life of dies.

In general, the tensile strength and reduction of area of a wire rod are in a proportional relationship, in which the lower the strength is, the lower the reduction of area becomes. By combining controlled rolling and controlled cooling, Kobe Steel has developed a wire rod having excellent drawability with reduced tensile strength, while maintaining a high reduction of area.

A torsion test is performed to evaluate the soundness of wire, in which vertical cracking, called delamination, occurs when a wire embrittled by the wire drawing is twisted.

**Fig. 9** compares the relationship between the true strain and the critical strain for delamination generation in a conventional steel to that of the newly developed steel. The newly developed steel exhibits no delamination at a higher wire drawing strain, demonstrating its excellent drawability.

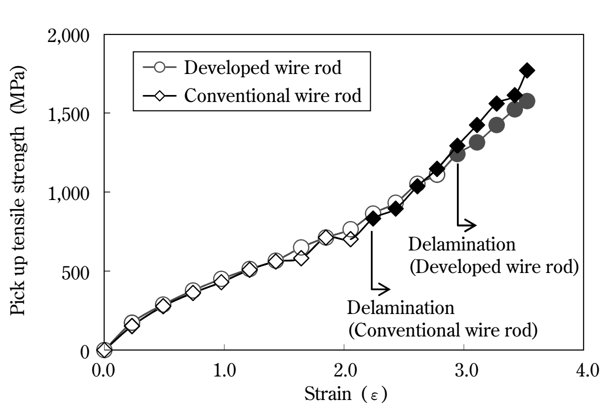

**Fig. 9** Relationship between strain and delamination

## 4. Future prospects

With its excellent characteristics, steel cord for tires has been playing an important role in traveling performance with its features including driving stability and weight reduction, which improves fuel economy. As the world focuses on the reduction of the global environmental burden, exhaust gas regulation in automobiles will become even more stringent, requiring higher strength steel cord that enables a further weight reduction in tires.

Increasing the strength of steel cord is an effective means for reducing the weight of tires; however, increasing the strength of a material increases its defect sensitivity. Thus, further reduction is required for defects such as non-metallic inclusions, segregation and surface scratches.

On the other hand, competition in the manufacturing of steel cord has become increasingly intense, requiring materials that contribute to cost reduction and productivity improvement.

In addition, the market for solar energy generation will continue to grow, which will further enhance competition among saw wire manufacturers and ingot cutting manufacturers. Cuttability, assured by high strength, and cutting yield, assured by small wire diameter, require a wire rod with high strength and fewer defects that can cause wire breakage, as in the case of steel cord application.

## Conclusions

Kobe Steel will strive to develop materials meeting the market needs and thus contribute to the growth of industries related to tires, automobiles and solar energy generation.

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