Higher Strength of Steel Hose Wire

Hose Manufacturers Conference
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I. Kiswire Group Overview

KISWIRE is world number one manufacturer in high carbon steel wire industry

Based on 2016

- **6,000** employees worldwide
- **USD 2.0 Billion** annual sales
- **1.2 million MT** annual production capacity
- **80+** supply countries
I. Kiswire Group Overview

- PC & Galv. Strand: 120,000 MT
- Conductor Wire: 10,000 MT
- Bead Wire: 380,000 MT
- Steel Cord: 350,000 MT
- Wire Rope: 130,000 MT
- Spring Wire: 140,000 MT
- Sawing Wire: 20,000 MT
- Hose Wire: 50,000 MT

Total: 1,200,000 MT/yr
I. Kiswire Group Overview

1. Automotive

**Cables**
- Sun Roof Cable
- Key Inter Lock Cable
- Clutch Cable
- Shift Lock Cable
- Accelerator Cable
- Hood Opener Cable

**Springs**
- Engine valve spring
- Clutch spring
- Pump & generator spring
- Suspension spring

**Tire Reinforcements**
- Steel cord
- Bead wire
2. Offshore

Wire Rope and Spiral strand

- Rope Diameter: 0.12mm ~ 180mm
- Weight, Max.: 600 ton/reel.
I. Kiswire Group Overview

3. Construction

- **Bridge wire**
- **World Cup stadiums**
- **PCCP wire**
  - Pre-stressed Concrete Cylinder Pipe
- **LNG tanks, nuclear power plants**
I. Kiswire Group Overview

4. Energy

- Flexible Pipe
- Super conductivity wire
- Saw wire
I. Kiswire Group Overview

◆ Production Range in Kiswire

Kiswire is now encompassing every kinds of steel wire product.
Ⅱ. Why Higher Strength of Hose Wire?

1. Hose Wire Production Process in Kiswire
1. Hose Wire Production Process in Kiswire

- **Wire Rod (raw material)**
  - Carbon Grade: 0.70~0.92%
  - Diameter: 5.5mm

- **Pre-Drawing**
  - Reduction of wire diameter through the conical shaped dies
  - Diameter: 1.0 ~ 2.5mm

- **Patenting**
  - Heat Treatment in order to restore fine pearlite

- **Plating**
  - Brass Coating to give adhesion to rubber
  - Brass thickness 1.0~2.5um, Copper composition 60~70%

- **Final Drawing**
  - Reduction of wire diameter through the conical shaped dies
  - Diameter: 0.2~0.8mm
II. Why Higher Strength of Hose Wire?

2. Trends in Hydraulic Hoses

- Higher in working pressure
- Lighter in hose weight
- Less reinforcement material
- Better in fatigue property
- Cost saving

Hose Wire with
- Higher Tensile Strength
- Higher Ductility
Ⅲ. Why Higher Strength of Hose Wire?

3. Strengthening Mechanism of Steel Wire

**Higher Tensile Strength by**

a. Increasing carbon content
   \[\triangle \sigma_1\]

b. Adding micro alloying elements
   \[\triangle \sigma_2\]

c. Higher cold working
   \[\triangle \sigma_3\]

Strain \([2\ln(d_0/d_1)]\)

- \(d_0\) : inlet dia.
- \(d_1\) : outlet dia.

Tensile strength

- 0.70% C
- 0.80% C
- 0.92% C + Cr
3. Strengthening Mechanism of Steel Wire

a. Effect of Carbon content

As Carbon added:

- **Advantage**
  - Tensile strength $\uparrow$
  - Hardness $\uparrow$
  - Wear resistance $\uparrow$

- **Disadvantage**
  - Elongation $\downarrow$
  - Reduction Area $\downarrow$
  - Carbon segregation $\uparrow$
  - Proeutectoid cementite $\uparrow$
3. Strengthening Mechanism of Steel Wire

b. Effects of micro alloying elements

![Graph showing the effects of micro alloying elements on the increment of tensile strength.](image)
3. Strengthening Mechanism of Steel Wire

b. Effects of micro alloying elements

- **Cr**
  : Fine Pearlite Lamellar Spacing (Photo.1)
  \(\rightarrow\) Good workability, high rate of work hardening and extended cold working limit

- **Si**
  : Solid-solution hardening,
  But the rate of work hardening is very low

- **V**
  : Precipitation hardening,
  But poor workability and low rate of work hardening.
3. Strengthening Mechanism of Steel Wire

b. Effects of micro alloying elements

- Pearlite Steel used for steel wire
  : Consists of layers or plates of Ferrite(Fe) and Cementite(Fe₃C)

[Photo.1] Pearlite Steel

[100 nm = 1 µm]
3. Strengthening Mechanism of Steel Wire

b. Effects of micro alloying elements

<table>
<thead>
<tr>
<th>Grade</th>
<th>C</th>
<th>Cr</th>
<th>Si</th>
<th>Mn</th>
<th>P</th>
<th>S</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal Tensile</td>
<td>0.68~0.72</td>
<td>≤0.05</td>
<td>0.12~0.30</td>
<td>0.03~0.60</td>
<td>≤0.025</td>
<td>≤0.020</td>
</tr>
<tr>
<td>High Tensile</td>
<td>0.80~0.84</td>
<td>≤0.05</td>
<td>0.12~0.30</td>
<td>0.03~0.61</td>
<td>≤0.025</td>
<td>≤0.020</td>
</tr>
<tr>
<td>Super Tensile</td>
<td>0.84~0.88</td>
<td>≤0.05</td>
<td>0.12~0.30</td>
<td>0.03~0.62</td>
<td>≤0.025</td>
<td>≤0.020</td>
</tr>
<tr>
<td>Ultra Tensile</td>
<td>0.90~0.94</td>
<td>0.15~0.25</td>
<td>0.12~0.30</td>
<td>0.03~0.63</td>
<td>≤0.025</td>
<td>≤0.020</td>
</tr>
<tr>
<td>Mega Tensile</td>
<td>0.98~1.02</td>
<td>0.15~0.25</td>
<td>0.20~0.50</td>
<td>0.03~0.64</td>
<td>≤0.025</td>
<td>≤0.020</td>
</tr>
</tbody>
</table>
3. Strengthening Mechanism of Steel Wire

c. Effects of cold working

True Strain \[2\ln(d_0/d_1)\]

[ The wire in the die, schematic ]
Ⅱ. Why Higher Strength of Hose Wire?

4. Better in Fatigue Property

Relation between Tensile Strength and Fatigue Limit

- Relation between $s_{TS}$ and $s_{FL}$

  ➔ Endurance ratio $[s_{FL} / s_{TS}]$

  for carbon steel

  0.4~0.6  $s_{TS} < 1400$ MPa
  0.2~0.4  $s_{TS} > 1400$ MPa

$S_{FL}$ (MPa) : Stress value at $1 \times 10^6$ cycles

$S_{TS}$ (MPa) : Tensile Strength
Fatigue strength increases as tensile strength increases.
But, with higher tensile strength, wire surface conditions become more critical to the fatigue strength. => Endurance ratio decreases with higher tensile strength
II. Why Higher Strength of Hose Wire?

4. Better in Fatigue Property

- Filament fatigue properties and its characteristics

- Low cycle fatigue test
  (C-type fatigue tester)

- High cycle fatigue test
  (Rotating Beam fatigue tester)
### Ⅱ. Why Higher Strength of Hose Wire?

4. Better in Fatigue Property

- **Filament fatigue properties and its characteristics**

<table>
<thead>
<tr>
<th></th>
<th>Low cycle fatigue property (Fatigue at plastic region, strain–life)</th>
<th>High cycle fatigue property (Fatigue at elastic region, stress–life)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fracture morphology</td>
<td>Tension side crack, Ductile tearing fracture, Compression side crack</td>
<td>Tensile tearing fracture, Crack initiation</td>
</tr>
<tr>
<td>Major influence factors</td>
<td>Crack propagation is the main factor. Surface characteristic is less important on the fatigue life. Ductile material enhance low cycle fatigue.</td>
<td>Crack initiation is the main factor. Surface characteristic is very important on the fatigue life.. Higher tensile enhance high cycle fatigue</td>
</tr>
<tr>
<td>Estimation</td>
<td>Fatigue life*</td>
<td>Fatigue strength**</td>
</tr>
</tbody>
</table>

* Value of fatigue cycle at which a specimen would fail at a given stress level.
** Value of stress at which a specimen would fail at a given fatigue life.
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1. How to increase wire ductility?

- **Delamination**

  Delamination is the longitudinal fracture or splitting of filament under torsional stress.

The occurrence of delamination decreases wire ductility.
1. How to increase wire ductility?

Prevent Delamination by

a. Reduce the amount of cold working
   ✓ Develop raw material

b. Reduce wire temperature at drawing
   ✓ Control drawing speed
   ✓ Control lubricant temperature

c. Develop process technology
   ✓ Homogeneous metal flow
   ✓ Control residual stress of drawn wire
1. How to increase wire ductility?

a. Develop raw material

- Co-Work with wire rod mill makers (POSCO, NSSMC)
  - High carbon steel
  - Alloy elements design
  - Control non-metallic inclusion
  - Optimized structure in fine pearlite
1. How to increase wire ductility?

b. Homogeneous metal flow

Scheme of wire plastic deformation in drawing die

Zone 1: Not yet deformed
Zone 2: Deforming plastically
Zone 3: Already deformed

The position at which the plastic deformation starts differs for the surface layer and the center of the wire, resulting in non-uniform deformation. Because the surface layer is more deformed, it is more work hardened. When non-uniform deformation occurs, there is a decrease in ductility.
1. How to increase wire ductility?

b. Homogeneous metal flow

Shape Factor ($\Delta$)

High $\Delta$: non-uniform deformation
Low $\Delta$: uniform deformation, but, too low, wire temperature goes up due to increased fraction length

By optimizing $\Delta$ parameter, homogeneous metal flow is guaranteed over the whole cross section

$\Rightarrow$ Better wire ductility
1. How to increase wire ductility?

b. Homogeneous metal flow

Lowering the reduction angle reduces the difference in hardness between the surface layer and the center of the cross section.

=> Better wire ductility

Influence of die reduction angles on the cross-section hardness difference between the surface layer and center of drawn wire
III. Obstructions to Higher Strength

1. How to increase wire ductility?

c. Control residual stress of drawn wire

Residual stress of drawn wire makes wire brittle.
Delamination can be prevented by controlling bending roll and back tension due to removing residual stress
=> Better wire ductility
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Kiswire has already developed UT grade on commercial base and now developing MT grade.