Effect of Thickness of Spring Wire on the Strength and Deformation Characteristics of a Spring Steel Conduit

Kris Sangthong, Wimonwan Ponuam and Rachsak Sakdanuphab*

College of Advanced Manufacturing Innovation, King Mongkut's Institute of Technology Ladkrabang, Bangkok, Thailand

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Abstract

In automotive industry, spring steel conduit is a main part of control cables in parking brake, tailgate and transmission. The structure of spring steel conduit consists of liner, steel wire and coating. The steel wire plays an important role in supporting cable exert the force. However, steel wire thickness is concerned with the mechanical strength, flexibility and production cost. In this work, the effects of steel wire thickness on mechanical and physical characteristics of spring steel conduit were investigated. The thickness of steel wire was varied from 0.3 to 0.6 mm. The analysis was performed by JASO T001-97 standard and Hooke's law was used to describe the spring steel conduit. The experimental result was confirmed by the compression testing and agreed with theoretical calculation. It was found that there was an increase in yield stress and young's modulus when the steel wire thickness increased. The compression force at yield that affects deformation in the spring steel conduit was also found. The deformation and stiffness were increased while the steel wire thickness increased. In addition, the minimization of steel wire thickness of 0.4 mm was obtained under JASO T001-97 standard, including the compression force at least 1,000 N and the safety factor of 1.5.

Keywords: Compression force, JASO T001-97 standard, tensile testing, spring steel conduit
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1. Introduction

Thailand ranks the 12^{th} largest automobile manufacturer in the world and Thailand is ASEAN's leader in the auto parts industry in 2017. The automobile and auto parts export value reach 19,844.69 million dollar with a 15.5% increase from 2016. The control cable manufacturing is one of the auto parts industries. It has an important role to control the mechanical systems of automobiles and motorcycles with a functional safety. The control cable such as parking brake [1-2], tailgate, hood release, fuel lid, door lock, transmission and seat cable are also composed of a spring steel conduit [3]. Due to the various applications, spring steel conduit was following a specification test standard such as ASTM, JASO and JIS. It can ensure vital features of spring steel conduit in consistent. In general, the material properties such as stiffness, light weight, toughness and resistance to tensile loading are concerned in the parts of spring steel conduit [4].

*corresponding author: E-mail: rachsak.sa@kmitl.ac.th

The strength and stiffness of component materials are usually of primary concern. It can be measured in terms of either the stress necessary to cause appreciable plastic deformation or the maximum stress that the material can withstand. Typically, high-strength steels have limited formability, bending and flexibility that decrease even more as strength increases. Thus, the size of material is becoming a critical condition [5-6]. For control cable, it is not only considered on the size of conduit, but also max stress must be considered due to the different functions of each control cable. For example, parking brake control cable has a higher max stress on their structure than the transmission control cable with a high operation forces on lever side. Therefore, the size of transmission control cable [7] is rather thicker than parking brake control cable around 2 mm for the same vehicle types.

In this study, we focus on the effects of steel wire thickness on strength and deformation characteristics of a spring steel conduit. Currently, the 0.6 mm of steel wire has also been used on the clutch control cable and throttle control cable. To provide the advantages of cost reduction, the steel wire thickness of 0.3 mm, 0.4 mm, 0.5 mm and 0.6 mm should be considered. Our experimental results were validated using the calculation based on Hooke's law. The analysis was performed by tensile testing machine under JASO T001-97 standard [8]. The standard determines the compression force must be at least 1,000 N and the safety factor of 1.5 is always taken. The experimental and theoretical analyses has been mentioned for mechanical and physical characteristics of spring steel conduit.

2. Materials and Methods

2.1 Spring steel conduit structure

The spring steel conduit has a standard design according to the JASO T 001-97 standard. The typical structure composes of liner, steel wire and coating as shown in Figure 1. The innermost of spring steel conduit is a liner which has an important role to reduce friction between inner wire and spring steel in the transmission of the push-pull force. A high strength steel wire is converted to a spring core, which is the main structure of spring steel conduit. It represents a flexible composite structure [9-11] with the axial spiral anisotropy of properties, formed by a lay of steel wire. Furthermore, it is suitable for installation onto a curved area. The coating is the outermost layer for protecting the main structure, including spring steel and liner from water, moisture and dust.

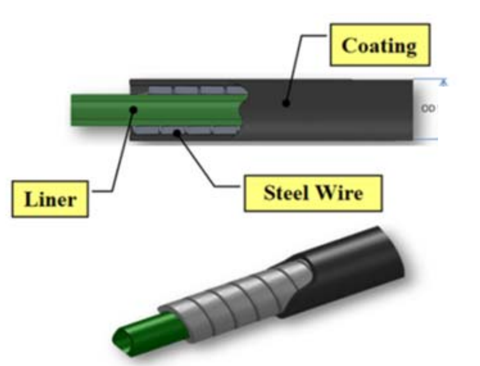
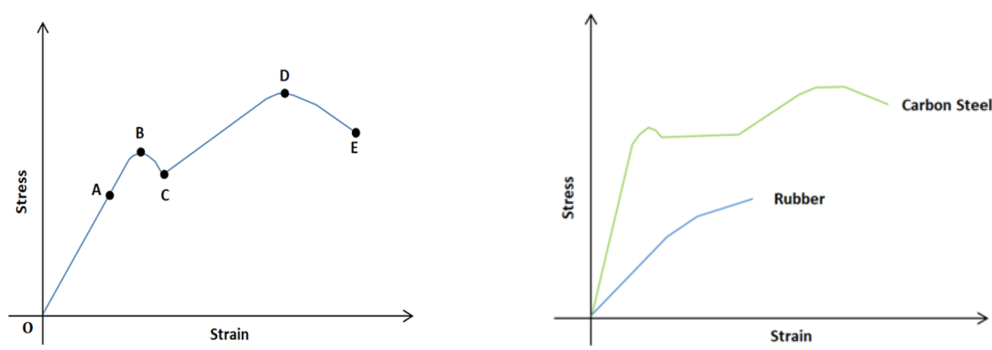


Figure 1. Structure of spring steel conduit consisting of liner, steel wire and coating

In the production, the spring steel conduit samples were made by the following 3 processes. Rolling is the process of reducing the thickness or changing the cross section of the steel wire. It is a critical process to make spring core using the different steel wire sizes. In the winding process, the steel wire was conducted into a squeeze roll throughout the die before rolling or wrapping around the liner feeder. The last process is a coating. Plastic is used to coat a spring steel conduit through the die injection with OD control around 5 mm. In general, plastic is usually used to coat the spring steel such as PP, PVC, PE and TPEE, etc. that depends on the application.

2.2 Theoretical analysis of spring steel conduits

Spring steel conduits or samples with different steel wire thickness were produced in the production process. The mechanical properties can be described by stress-strain curves [12-15]. The stress-strain relationship can be explained in Figure 2 (a). The stress-strain curves [16] with six different regions are consisted of proportional limit (OA), elastic limit (A), yield stress point or upper yield stress point (B), lower yield stress point (C), ultimate stress point (D) and breaking or rupture point (E). In elastic deformation, the stress-strain relationship is based on the Hooke's law (OA region). It can calculate the young's modulus of the samples to explain strength and stiffness. Figure 2 (b) shows the stress-strain curve with different material such as carbon steel and rubber. It can be clearly seen that the curves exhibit a different characteristic. Carbon steel has a tensile strength stronger than rubber. Carbon steel [17] is a strong material which is not ductile. It has a low stretch and break suddenly. It has a lot of elastic strain energy in a steel wire under tension. Rubber has a large strain for a small stress and it has a small elastic region.



(a) (b)

Figure 2. Stress-strain curves (a) stress-strain curve with different regions and points; (b) stress-strain curve with different material

The tensile test under JASO T 001-97 standards was employed on the samples for the mechanical response. It can predict the load that affects fracture or deformation in the samples. The analysis is based on stress-strain curve. The sample is experiencing a stress defined to be the ratio of the force (F) to the cross sectional area (A) of the spring steel conduit [1], following by

$$\sigma = \frac{F}{A} \tag{1}$$

Strain is the ratio between the deformation or the changes length (ΔL) with the original length (L_0) [18]

$$\varepsilon = \frac{\Delta L}{L_0} \tag{2}$$

In the low strain portion of the curves, most of materials obey Hooke's law. The stress is proportional to strain with the constant of proportionality being the young's modulus (*E*) [18,19]. Hooke's law along the z-direction, following by

$$E = \frac{\sigma_z}{\varepsilon_z} \tag{3}$$

Where E is Young's modulus, σ_z is the stress along the z-direction and ε_z is strain along the z-direction.

2.3 Material characterization

In general, the spring steel conduit was composed of several materials depend on the application. Polyethylene resin (PE)[20] is a general liner with a high-quality and low-density. The heat resistance is in the range of -40 to 80℃. The properties of PE resin are described in Table 1. High carbon steel wire or SWRH62A is also known as a black wire. It is a drawn steel wire which contains approximately 0.59% to 0.66% of carbon. The chemical compositions of each element are specified in Table 2, following by JIS G 3506: 2004 standards. Polypropylene (PP) [21] resin is used to coat the spring steel wire. The heat resistance is in the range of -40 to 140℃. The density of PP is between 0.895 and 0.92 g/cm^3. Therefore, PP is the commodity plastic with the lowest density. The properties of PP resin that we used in this study were referenced by ASTM standard as shown in Table 3.

Our experiment was validated by theoritical calculation based on Hooke's law to confirm the validity of tensile testing. The thickness of steel wire was varied from 0.3 mm to 0.6 mm. The stress, strain, young's modulus, yield stress, compression force, deformation and stiffness were presented and discussed. In addition, the JASO T 001-97 standard was taken into account.

Table 1. The properties of PE resin used in this study were referenced by ASTM standard.

Item	Specification	Unit	Method
Density	0.09 ± 0.02	g/cm^3	ASTM D 1505
Tensile Strength	≥ 14	MPa	ASTM D 638
Elongation at Break	≥ 320	%	ASTM D 638
Shore Hardness D Scale	55~69	D scale	ASTM D 2240

Table 2. The properties of high carbon steel wire used in this study were referenced by JIS G 3506: 2004 standard.

Symbol of Grade	Fe	C	Si	Mn	P	S
SWRH62A	97.79	0.59~0.66	0.15~0.35	0.30~0.60	0.30 max	0.30 max

Table 3. The properties of PP resin used in this study were referenced by ASTM standard.

Item	Specification	Unit	Method
Density	0.09 ± 0.02	−	ASTM D 1505
Ash Constant	−	%	Firing
Tensile Stress at Yield	≥ 14	MPa	ASTM D 638
Elongation at Break	≥ 320	%	ASTM D 638
Durometer Hardness D Scale	55~69	D scale	ASTM D 2240
Flexural Modulus	390~690	MPa	ASTM D 790

3. Results and Discussion

The experimental results were carried out by compression testing machine to evaluate mechanical characteristic of spring steel conduit. The stress-strain curves of the samples with different thicknesses of steel wire are presented in Figure 3(a). The results show that the thickness of steel wire directly affected their mechanical behavior such as elastic deformation, first defect and plastic deformation. The first defect is defined as a point which is linearity loss and start of damage in the spring steel conduits. Figure 3(b) shows the example of the first defect on 0.5 mm steel wire thickness. It is occurring at 3.73% strain. It causes by the distortion, but the sample is still usable. The plastic deformation of 0.5 mm steel wire thickness is shown in Figure 3(c). The plastic deformation is the permanent distortion that occurred by the compressing, stretching or twisting during the compression testing and is not available. Their characteristics are similar to those of carbon steel as seen in Figure 2(b). The strain energy in steel conduits under compression force can be calculated by $U = V\sigma^2/2E$ when V defines as a volume of the body, σ is a strain and E is Young's modulus [22]. The strain energy is the energy stored by a sample undergoing deformation. The highest strain energy of 1092.71 Jmm^{-3} was obtained for steel wire thickness of 0.6 mm. This result shows that the thickness of steel wire directly affects the mechanical performance of spring steel conduit.

The simulation of the stress as a function of compression force and the measured yield stress are shown in Figure 4. Note that, yield stress is defined as a compression force at yield per cross-section area of the wire thickness. The yield stress relates to the stress at which sample changes from elastic deformation to plastic deformation. It can be seen that the measured yield stress was aligned on the simulation curves. The simulation was obtained using the compression force from 750 N to 2200 N. A linear relation is obtained between the stress (σ) and the compression force (F). The relationships are followed by $\sigma_{0.3mm} = 0.0687F$, $\sigma_{0.4mm} = 0.0640F$, $\sigma_{0.5mm} = 0.0618F$ and $\sigma_{0.6} = 0.0606F$.

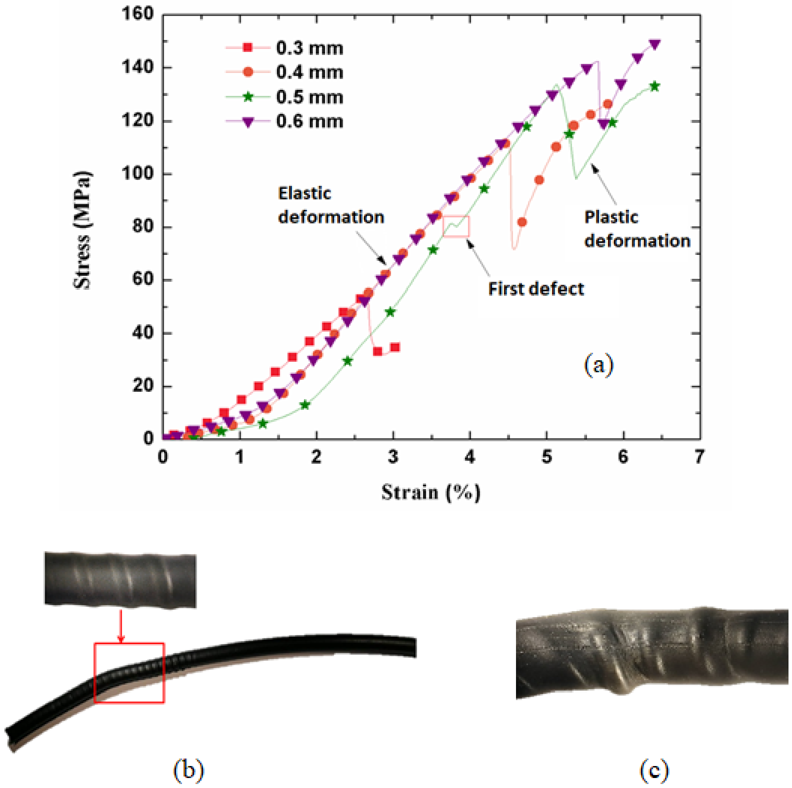


Figure 3. (a) Stress-strain curves with the different steel wire thickness (0.3 mm to 0.6 mm)
(b) First defect of 0.5 mm steel wire thickness
(c) Plastic deformation of 0.5 mm steel wire thickness

Table 4. Mechanical properties of spring steel conduit with different steel wire thicknesses.

Steel wire thickness (mm)	**Elastic Modulus (MPa)**	**Stress at first defect (MPa)**	**Yield stress (MPa)**
0.3	21.664	36.587	53.637
0.4	29.204	56.090	112.036
0.5	29.221	81.235	133.761
0.6	30.515	129.363	141.608

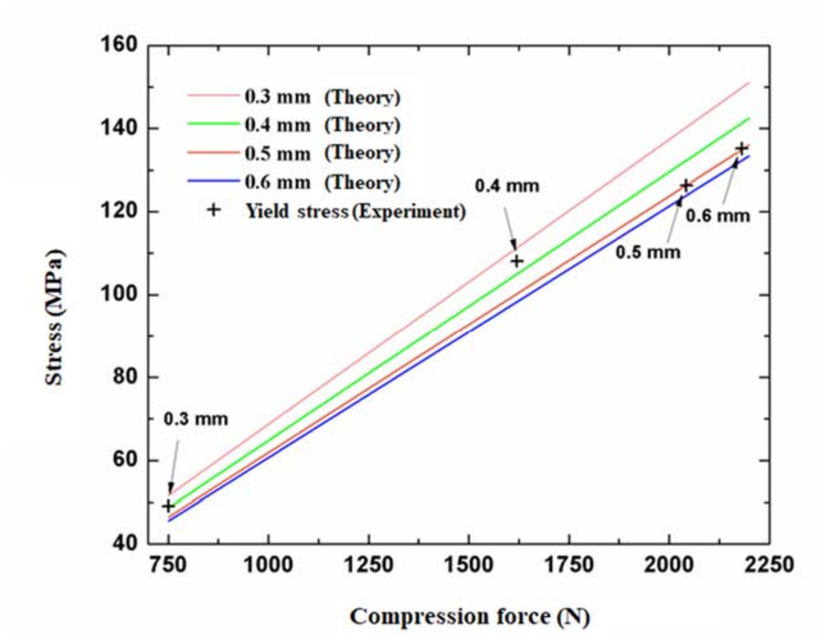


Figure 4. Comparison between theoretical and experimental results of yield stress as a function of compression force with four difference steel wire thickness between 0.3 mm to 0.6 mm.

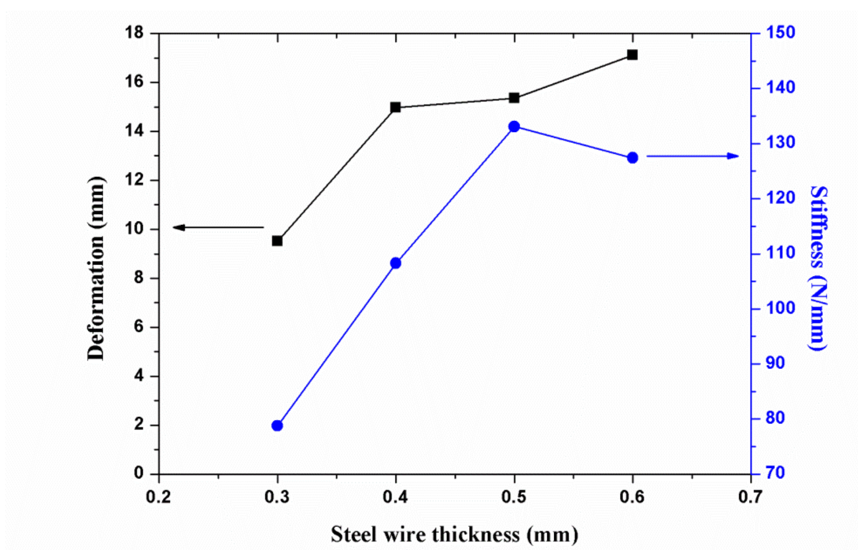


Figure 5. Deformation and stiffness as a function of steel wire thickness from 0.3 mm to 0.6 mm.

For the compression testing, the deformation behavior is proportional to the stress that applied within the elastic range of the material. It has begun to permanently deform and lose their functional working when it is out of range. For the spring steel conduit, the deformation is caused by the change of steel wire structure on the stages of damage in bending to broken. Thus, it can be clearly seen and calculated by the change of length of the spring steel conduit (ΔL). It is related to the stiffness of the material structure. It is defined as the properties of a material which is rigid and difficult to bend under force enhancement. It can be returned to original shape once the load is removed. Stiffness (k) [23] is associated with elastic deformation following by

$$k = \frac{F_{\max}}{\Delta L}$$

where F_{max} is the maximum force (refer to the force at yield point).

The deformation and stiffness as a function of steel wire thickness are shown in Figure 5. The deformation and stiffness characteristics of the spring steel conduit were in the same manner. The deformation increases from 10 mm to 17 mm as the wire thickness increases from 0.3 to 0.6 mm. The stiffness increases from 78 N/mm to 132 N/mm as the wire thickness increases from 0.3 to 0.5 mm and then the stiffness slightly decreases to 128 N/mm at 0.6 mm. The stiffness is the ability of the sample to resist deformation. The high thickness of steel wire is needed in order to achieve the high stiffness of spring steel conduit and to avoid bends and deformation.

Figure 6 shows the safety factor and compression force at yield point as a function of steel wire thickness. It was found that the yield force increases from 750 to 2,181 N as the steel wire thickness increases from 0.3 to 0.6 mm, respectively. From JASO T 001-97 standard, the compression force must be at least 1,000 N and the safety factor of 1.5 is always taken. Generally, the increase in steel wire thickness resulted in a linear increase in yield stress. Both conditions are required in order to optimize the spring steel conduit. Thus, it does not signify with the steel wire thickness less than 0.4 mm due to the lower safety factor. Currently, the 0.6 mm of steel wire is also used in the control cable manufacturing. To provide the advantages of cost reduction, the steel wire thickness of 0.4 mm should be considered. It has a safety factor of 1.62 and compression force of 1,620 N that passed a standard design.

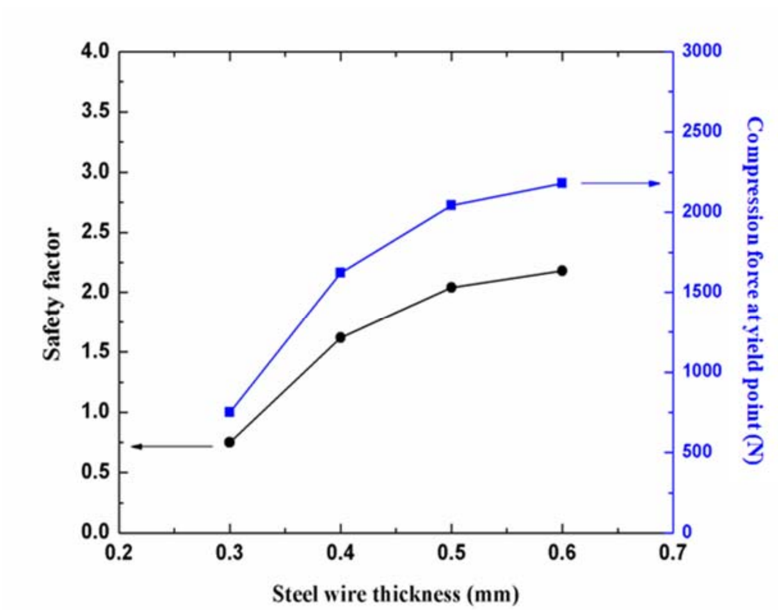


Figure 6. A safety factor and compression force as a function of steel wire thickness from 0.3 mm to 0.6 mm.

4. Conclusions

The mechanical characteristics of spring steel conduit was analysed by compression testing with the steel wire thickness varying from 0.3 mm to 0.6 mm and optimization under JASO T001-97 standard. Currently, the 0.6 mm of steel wire has also been used in the control cable manufacturing while the minimization of steel wire thickness of 0.4 mm was obtained. The mechanical parameters such as elastic modulus, first defect and yield stress were presented. The experimental results were compared with the theoretical calculation. The agreement between the two results confirms the validity of the compression testing.

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