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High Strength Steel Tubes for Automotive Suspension Parts —High Strength Steel Tubes with Excellent Formability and Forming Technology for Light Weight Automobiles—[†]

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Abstract:

JFE Steel has developed two kinds of 780 MPa class steel tubes for automotive suspension parts. They have excellent formability, fatigue endurance, toughness and paintability. In addition to the material development, tube forming and its evaluation techniques are also important for applying high strength steel tubes to actual parts. The effects of forming conditions and mechanical properties on formability in bending, nosing and hydroforming are also discussed.

1. Introduction

Welded steel tubes have closed cross sections that are of lightweight while being highly rigid. With the advance in forming technologies such as tube hydroforming, the welded steel tubes are being increasingly used as automotive structural parts such as sub-frames. To meet the demand from the automotive sector, JFE Steel is systematically developing new materials and products as well as secondary tube forming technology and performance evaluation technology as shown in **Fig. 1**. To date, the company has successfully developed unique steel tubes such as a new electric resistance welded (ERW) tube that is highly formable[1)] and HISTORY tube that makes use of stretch reducing as a means of controlling the microstructure (HISTORY: high-speed tube welding and optimum reducing technology).[2–4)] The company has also provided customers with forming technology[5)] and numerical analysis technology[6)] suitable to each structural part. In recent years in particular, the development of steel tubes that have high strength as well as high formability is being increasingly required. They are expected to be used as suspension parts such as suspension arms and torsion beams, and contribute to the further improvement in fuel economy and maneuverability of automobiles. The new ERW tube and HISTORY tube, both with 780 MPa class tensile strength, were developed for use as suspension and chassis parts. This paper

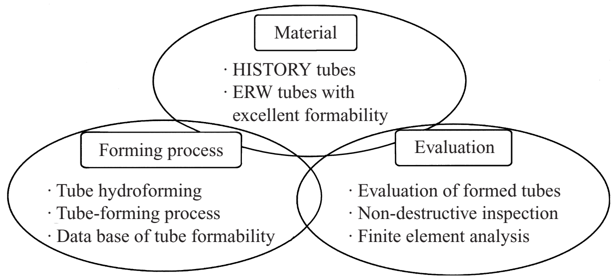

Fig. 1 Schematic description of correlated development items for tube applications to automotive structural parts

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presents the excellent formability and practical features of these steel tubes. When the configurations of the parts to be made of the high strength steel tubes as well as the processes for forming them are being designed, the unique forming properties of these materials need to be considered. Hence, the effects of forming conditions and material properties on formability in bending, nosing, and bulge forming processes are also discussed.

2. New 780 MPa Class ERW Tube

When planning to use steel tubes as suspension and chassis parts, serious consideration needs to be given not only to their formability, but also practical features such as fatigue endurance, toughness, paintability, and property constancy. JFE Steel developed a new 780 MPa class ERW tube through clarifying the metallurgical factors that affect formability and these practical features. It is produced making full use of the state-of-the-art technologies as represented by high purity ladle metallurgy in steelmaking; high precision controlled cooling in hot rolling; and high precision online post annealing treatment of the weld seam. The chemical composition and microstructure of the tube material are optimized through these means. The concept applied to developing the material properties of this new ERW tube is summarized in **Fig. 2**.

With regard to high-strength steel sheets, the best way to realize the well-balanced strength and formability is the use of a composite microstructure consisting of hard phase (e.g., martensite and retained austenite) and ferrite phase.[7] In contrast, this tube uses a microstructure mainly consisting of ferrite and bainite to reduce the hardness difference between the phases. Through this means, the strain to be generated during tube forming is prevented from concentrating in the soft phase. Thus, excellent ductility was realized allowing the tube to be bent with a radius of less than 2*D* (*D*: outer diameter of the tube) as required to the material for forming auto parts. This homogeneous microstructure has an advantage that it does not require much addition of

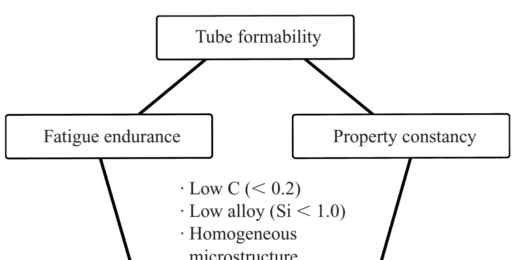

Fig. 2 Concept of developed 780 MPa ERW steel tubes

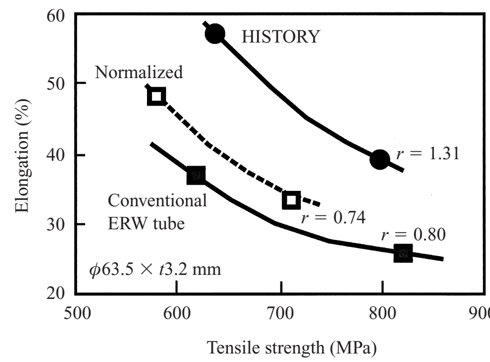

Fig. 3 TS-El balance and *r*-value of 780 MPa HISTORY

Si and other alloying elements as the composite microstructure. It also contributes to the realization of excellent fatigue endurance, toughness, paintability, and property constancy.

3. 780 MPa Class HISTORY Tube

JFE Steel has developed a 780 MPa class HISTORY tube for parts that require higher formability. The relation between tensile strength and elongation for 590 to 780 MPa class steel tubes is shown in **Fig. 3**. Compared with the conventional as-rolled or normalized ERW tubes, the 780 MPa class HISTORY tube exhibits higher elongation. Its *r*-value is also higher. The excellent elongation and *r*-value are realized because the microstructure is made finer and more uniform due to stretch reducing, turning it into a textured structure unique to this tube rolling method.[3] The HISTORY tube with such high elongation and *r*-value causes smaller reduction in wall thickness when bent, and is expected to have excellent properties in static strength and fatigue endurance in bent areas. As in the aforementioned 780 MPa class ERW tube, practical features such as toughness and paintability are secured for the 780 MPa class HISTORY tube as well through assigning it a chemical composition low in carbon content and making its microstructure homogeneous and fine. Furthermore, the manufacturing method was adopted paying special attention to dimensional accuracy.

4. Practical Features of Newly Developed 780 MPa Class Steel Tubes

4.1 Fatigue endurance

The fatigue endurance of the newly developed 780 MPa class steel tubes was evaluated by the 4 point bending fatigue test. As shown in **Fig. 4**, both 780 MPa class ERW tube and HISTORY tube exhibit fatigue strength as high as 0.8 in terms of the ratio between the 2×10^6 cycle fatigue strength and tensile strength. The

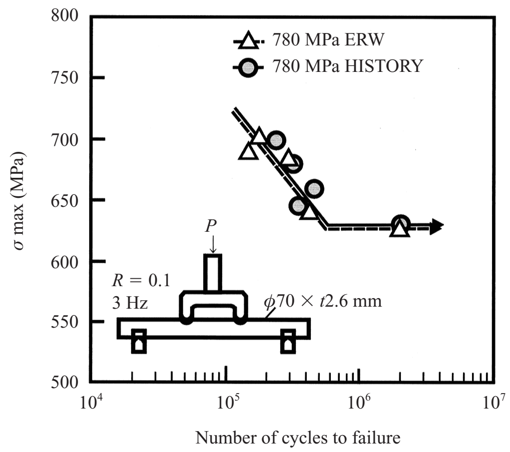

Fig. 4 Fatigue endurance (*S*-*N*) curves of developed 780 MPa ERW steel tube and 780 MPa HISTORY in 4-point bending fatigue test

HISTORY tube exhibits high fatigue strength without the YS increase by the tube forming strain because it has a high work hardening property and the propagation of cracks is effectively suppressed.

In the HISTORY tube, the material properties of the weld seam area and base metal area are homogenized by the heat treatment applied before the stretch reducing process. In the new 780 MPa class ERW tube, on the other hand, the material properties of the weld seam area and base metal area are homogenized by the on-line heat treatment of the weld seam area. Fatigue test spesimens were taken out of the weld seam area and the base metal area of the 780 MPa class ERW tube in the circumferential direction after being cut and extended flat. They were subjected to the plane bending fatigue test under the conditions of fully alternating loads at a stress ratio (R) of -1 and frequency of 25 Hz. As shown in **Fig. 5**, the weld seam area gave excellent fatigue strength equivalent to that of the base metal area.

Arc welding was performed on the newly developed 780 MPa class ERW and HISTORY tubes under the conditions simulating the assembling of auto suspension parts for evaluating the properties of the welded area.

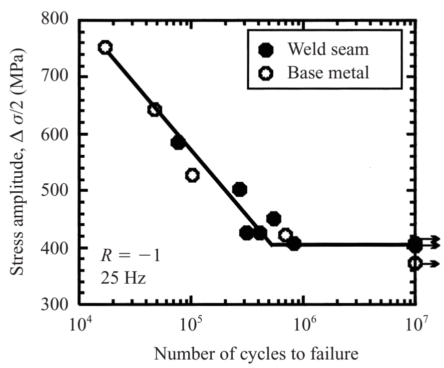

Fig. 5 Fatigue endurance (*S*-*N*) curves of weld seam and base metal in 780 MPa ERW steel tube

The welded area did not show any softening that might pose problems in practical application and had excellent fatigue endurance. When the welded joint area was subjected to the static tensile test, rupture occurred in the base metal area, demonstrating the sufficient strength secured at the welded area.

4.2 Toughness

Auto suspension and chassis parts are required to have resistance to external impact force exerted at the time of collision. For both types of newly developed steel tube, excellent impact resistance and low temperature toughness are secured by an optimum control of chemical composition and microstructures including suppression of carbon content. The 1/4 sized Charpy test pieces with 2 mm V notches were taken out of the tubes and extended flat to evaluate toughness. Both types of newly developed steel tube gave the absorbed energy values exceeding 120 J/cm^2 at 0°C in either of L and C directions, and the fracture appearance transition temperature of lower than -70°C, demonstrating excellent impact resistance and low temperature toughness.

4.3 Paintability

For both types of newly developed 780 MPa class steel tube, excellent paintability is secured by providing them with chemical compositions with the reduced contents of Si or other alloying elements as well as microstructures that are homogeneous and fine. The tests for evaluating phosphatability and the wet adhesion property as well as the salt spray cyclic corrosion test were performed in accordance with the conditions reported in the reference.[8)] The results were compared with those of the 370 MPa class ERW tube (**Table 1**). Phosphatability was evaluated by observing the condition of phosphate crystals; wet adhesion by cross scoring tests; and corrosion resistance by measuring the creepage width after the salt spray cyclic corrosion test over electrodeposited paint coating. All of the results confirmed that both types of newly developed 780 MPa class steel tube have excellent properties equivalent to those of the 370 MPa class ERW tube in terms of phosphatability, wet adhesion, and corrosion resistance after painting.

Table 1 Paintability of 780 MPa ERW steel tube and 780 MPa HISTORY

Grade	Phosphatability	Wet adhesion*	Corrosion resistance** (ED***: 10 μm)
780 MPa ERW	○	○	○
780 MPa HISTORY	○	○	○
STKM13A	○	○	○

* 40°C, 500 h, ** 5%NaCl-35°C, 480 h, *** With cross cut, ○ : Good

4.4 Property Constancy

The auto suspension and chassis parts are required to have constancy in material properties in view of preventing spring back and securing functions as component parts. For the new 780 MPa class ERW tube, highly constant material properties equivalent to those of the highly formable 780 MPa class hot rolled steel sheet, NANOHITEN,[9] are secured by employing new technologies such as high precision controlled cooling after hot rolling. For the 780 MPa class HISTORY tube, property constancy is secured by applying high precision control to the chemical composition and to the temperature and forming conditions in the stretch reducing process.

5. Formability of High Strength Steel Tubes

In recent years, steel tubes have been gathering attention as materials for forming auto parts and numerous investigations of the practical application of the tube hydroforming (THF) technology have been reported. The THF is a compound tube forming process that includes bending and other preliminary tube forming, hydraulic pressure tube forming, and die less piercing under high hydraulic pressure. As such, information on the formability of a material under various forming methods is indispensable for the successful application of the THF technology. The materials most commonly applied to the THF are of the STKM-11A (290 MPa class) to 13B (440 MPa class) grade. The steel tubes for automotive application with these strength levels are generally easy to form, and numerous reports have been published on the expandability of material tubes.[5] However, when using a high strength steel tube with strength exceeding these levels, it becomes important to select optimum forming conditions taking into account the specific formability of the material, since the formability decreases with the increase in strength. Furthermore, the added increase in strength due to work hardening needs to be fully taken into account in order to secure the expected functionality as auto parts. Other factors to be considered include the effect of wrinkles caused by forming. Hereunder, with regard to high strength steel tubes, on which much has not been reported to date, the effects of forming conditions and material properties on formability are discussed. The discussion is centered on three types of forming process most commonly applied in the secondary forming of automotive steel tubes: bending, swaging, and bulge forming.

5.1 Bending Property

Rotary draw bending is the most common method employed for bending automotive steel tubes. In this bending method (**Fig. 6**), the wiper is used to prevent wrinkle generation inside the bending curvature, and the back boost load is applied to suppress thickness reduction outside the curvature. These means allow the tube to be bent with a comparatively small radius. The ratio of the bending radius of the neutral axis against the outer diameter of the material tube (R/D) has a relation with the geometrical elongation (ε) outside the bending curvature as follows: $\varepsilon = (D/2R) \times 100$. Therefore, the value of ε is 25% at $R/D = 2.0$, increasing to 33% at $R/D = 1.5$ and further reaching 50% at $R/D = 1.0$. Thus, to prevent rupture along the outside of the bending curvature while performing small radius bending, it is particularly important to secure the ductility of the material tube and suppress thickness reduction through optimizing the forming conditions.

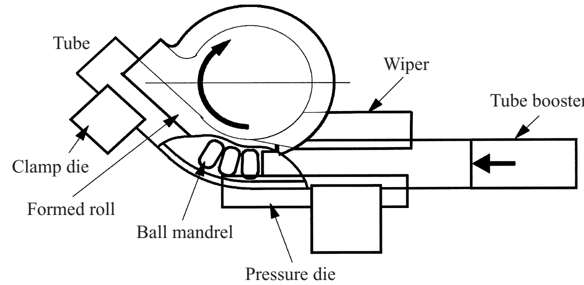

Fig.6 Schematic illustration of rotary draw bending

The results of the rotary draw bending test performed on various steel tubes with different strength levels and heat treatment histories are shown in **Table 2**. In these tests, lubricant was applied over the ball mandrel to enable a comparison of the bending performance of various materials with widely different material properties. With all of the 440 and 590 MPa class steel tubes, except the 590 MPa class as-rolled ERW tube, it was possible to perform small-radius bending down to where the bending radius of the neutral axis is equivalent to the outer diameter of the material tube (1D). Among the 780 MPa class steel tubes, small radius bending down to around

Table 2 Rotary draw bendability of steel tubes (⌀63.5 × t3.2 mm)

TS grade (MPa)	Tubes	Bending radius, ρ/D			
		2.0	1.5	1.0	Remarks
440	HISTORY	○	○	○	–
	Normalized ERW	○	○	○	–
	As rolled ERW	○	○	○	–
590	HISTORY	○	○	○	–
	Normalized ERW	○	○	○	–
	As rolled ERW	○	○	×	–
780	HISTORY	○	○	×	1.1: ○
	Normalized ERW	○	○	×	1.3: ○
	As rolled ERW	○	△	×	–

○ : Without split, △ : Necked, × : Split

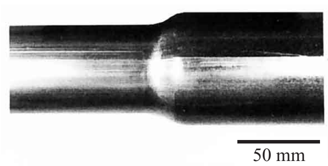

Photo 1 20% swaged 780 MPa ERW steel tube (ø76.3 × t2.9 → ø60.5 mm; 1 pass)

1.5D was possible with the as-rolled ERW tube; down to 1.1D with the HISTORY tube; and down to 1.3D with the normalized ERW tube. Comparing these results with Fig. 3, the difference in the forming limits is attributable to the difference in the n- and r-values of the materials.[5, 6, 10, 11]

5.2 Nosing Property

Nosing and flaring are technologies frequently applied for forming the tube ends. Two methods are commonly applied for nosing: one is rotary swaging and the other is parallel swaging where a material tube is pushed into a die cavity.[12] Since the stress field generated in the swaging process is mostly composed of compressive stress, these processes are characterized by the fact that it does not pose problems of cracking and a large swaging ratio is easily obtained. In the parallel swaging method, lubricant needs to be used for the tube to pass through the die without seizure. This method is widely adopted because it has advantages over the rotary swaging in which the required equipment is economical and the level of noise generated during processing is low.

The new high strength ERW tubes were experimentally processed by the parallel swaging method. The decreasing ratio of outer diameter as large as 20% was achieved in one pass even with the 780 MPa class ERW tube (**Photo 1**). It was also confirmed that the similar parallel swaging method is applicable to the HISTORY tube. The HISTORY tube tends to have a smaller ratio of thickness increase at the swaged position. This is presumably attributable to the microstructure unique to the HISTORY tube.

5.3 Bulge Forming Property

The 780 MPa class HISTORY tube and 690 MPa class ERW tube were experimentally subjected to bulge forming. The results are shown in **Table 3**. In the case of free bulging without the use of a die, the expansion limits of these high strength steel tubes were about half those of the 370 MPa class ERW tubes regardless of whether they were formed with or without axial feeding.[13] On the other hand, in the case of bulging in dies with high pressure of a rectangular cross-section, the 780 MPa class HISTORY tube was successfully bulged to an expansion ratio of 35% without causing any split

Table 3 Hydroformability of steel tubes (ø63.5 × t3.2 mm)

Grade	Expansion limit in free bulge (%)		Expansion results in die cavity*		
	Without axial displacement	With axial displacement	Split	Wrinkle	Hydroformed corner radius (mm)
780 MPa HISTORY	8	35	None	None	18.5
690 MPa normalized	5	23	None	Exist	16.1

* Maximum expansion ratio: 35%, Axial displacement: 60 mm, Internal pressure: 200 MPa

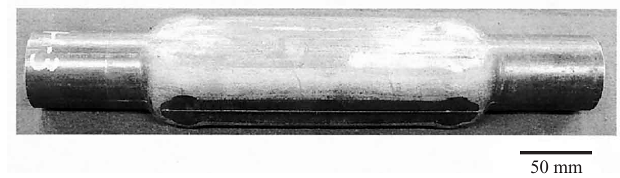

Photo 2 Hydroformed 780 MPa HISTORY in die cavity (ø63.5 × t3.2 mm → 35% expansion)

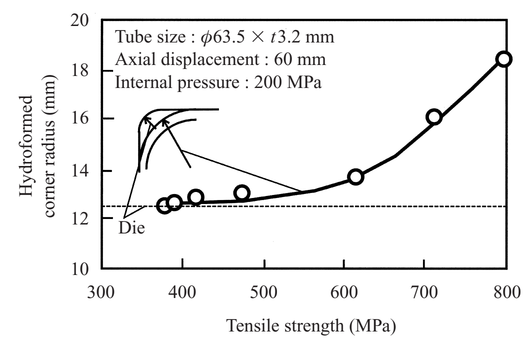

Fig.7 Effect of tensile strength on hydroformed corner radius in die cavity

or wrinkle, making full use of the restraint imposed by the axial displacement and the die, even though the corner radius was large (**Photo 2**). The relation between the tensile strength of the material tube and the corner radius after the completion of bulging in dies is shown in **Fig. 7**. When the bulge forming conditions are constant, the corner radius after forming is closely related to the tensile strength of the material tube regardless of the n- and r-values.

6. Conclusions

Two types of 780 MPa class steel tube were developed for use in automotive suspension and chassis parts, and their formability and practical features were evaluated.

(1) For both the 780 MPa class ERW tube and the 780 MPa class HISTORY tube, excellent formability enabling bending by a radius of less than 2D (D: outer diameter of the tube), excellent fatigue endurance, toughness, and paintability were secured in a

stable manner through assigning them chemical compositions low in carbon content and making their microstructure homogeneous and fine. In particular, the 780 MPa class HISTORY tube has formability as high as 35% or more in the elongation and 1.2 or more in the *r*-value.

(2) With regard to bending, nosing, and bulge forming, the three types of forming processes most commonly applied in the secondary forming of automotive steel tubes, the newly developed steel tubes were subjected to forming experiments systematically changing the forming conditions and material properties. The forming limits of the high strength steel tubes up to the 780 MPa class were clarified.

(3) The applicability of these newly developed 780 MPa class steel tubes to suspension arms and other auto parts was confirmed by the evaluation test performed by customers and they are now being used in actual vehicles.

JFE Steel will continue to develop new high strength steel tubes that have innovative functional properties and high reliability aiming at the application in automotive suspension parts. The company will also continue to develop technologies for forming and numerically analyzing these steel tubes. Through these developments, the company intends to meet the needs of environmental protection by making automobiles lighter in weight and securing crashworthiness by improving the rigidity of auto parts.

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