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Development of High Carbon HISTORY Steel Tube with Excellent Formability*



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Synopsis:

Kawasaki Steel has developed the HISTORY process as a next generation technology of manufacturing electric resistance welded steel tubes. Steel tubes with excellent properties can be produced by warm-reducing process which is put into practice in the HISTORY process for the first time in the world. In high carbon steel tubes, spheroiding of cementite that takes some hours in conventional annealing methods can be completed in several seconds by warm-reducing process. This effect of warm-reducing process makes it possible to produce high carbon steel tubes of excellent formability with high productivity. The high carbon HISTORY steel tube having excellent formability enables cold forming of complicated shapes and reduced working force in cold working.

1 Introduction

In the automotive industry, hollow parts made from electric resistance welded (ERW) steel tubes have progressively been adopted in parts such as stabilizers and drive shafts in order to satisfy the mutually contradictory requirements of high rigidity and weight reduction.[1] Because these parts require extremely high fatigue strength, they are manufactured by repetitive quenching and tempering of high carbon steel. On the other hand, ERW tubes for these applications show considerable work hardening and quenching hardening of the seam as a result of the pipemaking process. For such applications, forming and heat treatment are necessary after pipemaking.

Normalizing is generally performed as a heat treatment for high carbon steel.[2] However, even if normalizing is done, it is not necessarily possible to obtain adequate formability because the microstructure of high carbon steel contains a large amount of pearlite. Cementite spheroidizing annealing improves formability, but the heat treatment time is long, for several hours,[3] and the material is prone to decarburization and similar problems.

Moreover, small-diameter, thick-walled tubes are generally used in parts such as stabilizers and drive shafts. However, tube shape forming of small-diameter thick-walled ERW tubes is difficult, which causes problems in the manufacturing process. For this reason, there had been limitations on the sizes which could be used in hollow parts.

Kawasaki Steel developed the HISTORY process as a next-generation ERW tube manufacturing technology. In this process, warm-reducing was applied to ERW tubes for the first time in the world, making it possible to manufacture steel tubes with numerous new functions. As one important advantage of this process, cementite spheroidizing can now be performed in a remarkably short time. It is also possible to produce small-diameter, thick-walled ERW tubes easily because products are warm-reduced from large-diameter mother tubes. The features of the newly developed steel tubes are described in this paper.

2 Spheroidizing of Cementite by Warm-Reducing Process

Spheroidizing of the pearlite phase to form cementite is an effective technique for improving the cold workability of high carbon steel. For this purpose, tubes are generally held for several hours at a temperature of around 700°C. However, this technique is difficult to apply as a standard mass-production process for steel

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tubes. Thus, a technology which makes it possible to complete this process on-line by shortening the spheroidizing time was desired.

Separating out the cementite contained in the pearlite phase by mechanical or thermal means is considered an effective technique for shortening the spheroidizing time. Two techniques which effectively shorten the spheroidizing time are known, these being cold working before annealing and partial solute treatment of the cementite in the pearlite by heating to above the A_1 transformation temperature before spheroidizing annealing.[3)] Because the warm-reducing process combines these two methods, it was considered possible to achieve spheroidizing in a short period of time by applying this technology.

Therefore, the effect of warm-reducing on the shape of cementite was investigated. The samples used were 0.3%C-0.2%Si-0.8%Mn steel. Reducing was performed at the heating and finishing temperatures shown in the equilibrium phase diagram in **Fig. 1**. The starting points of the respective arrows in Fig. 1 indicate the corresponding heating temperatures, and the end points of the arrows are the finishing temperatures. From this figure, it is possible to estimate what type of microstructure is formed by rolling or other processing. **Photo 1** shows the microstructures after completion. Spheroidizing of the cementite proceeded more strongly at lower reducing temperatures, and when the finishing temperature was lower than the A_1 transformation temperature (approximately 720°C), it was possible to spheroidize the cementite in a rolling time of only a few seconds. This effect is considered to be the result of thermal or mechanical separation of the cementite contained in the pearlite, as discussed above, by first heating to above the A_1 transformation temperature, and then rolling at below the A_1 transformation temperature.

Furthermore, work hardening due to reducing is comparatively small at temperatures below the A_1 transformation temperature. This means that the improved formability obtained by cementite spheroidizing as described above can be utilized even with as-rolled products.

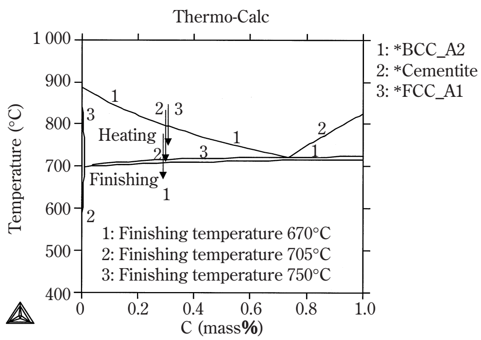


Fig. 1 Reducing temperature and calculated Fe-C-0.2%Si-0.8%Mn phase diagram

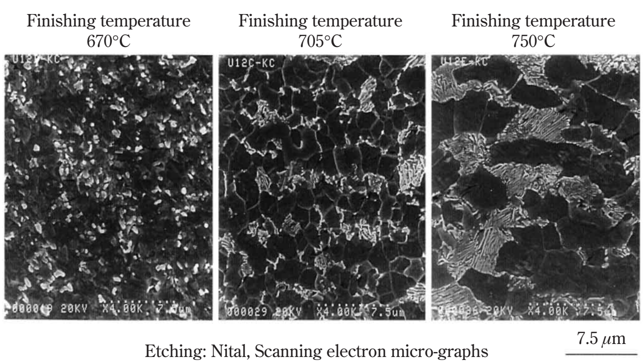


Photo 1 Effect of reducing temperature on microstructure

3 Formability of Newly Developed Steel Tube

3.1 Tensile Properties

Hot rolled steel sheets of the chemical composition shown in **Table 1** were formed into ERW tubes, which were then warm-reduced. A tensile test was conducted, and the microstructure and texture were observed. To compare tensile properties, ERW tubes of the same chemical composition were also treated by normalizing.

For the tensile test, JIS12 A tensile test pieces were taken from the pipe longitudinal direction. Strain gauges were attached in the longitudinal direction and transverse direction, and the r-value was calculated from the inclination between the longitudinal strain and the transverse strain when strain in the longitudinal direction was in the range of 6–7%.

Figure 2 shows a comparison of the tensile properties of the warm-reduced ERW tube and normalized ERW

Table 1 Chemical composition (mass%)

C	Si	Mn
0.42	0.2	1.4

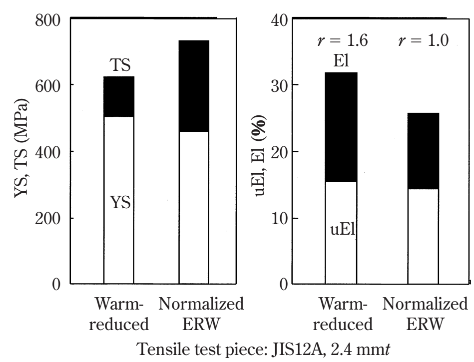


Fig. 2 Tensile properties of warm-reduced high carbon steel tube

tube. In comparison with the normalized ERW tube, the strength of the warm-reduced material is low and its elongation is high. The *r*-value of the warm-reduced tube is also higher. Where elongation is concerned, the improvement in uniform elongation, uEl, was slight in the warm-reduced tube, but the improvement in local elongation El-uEl was remarkable. This effect was attributed to improved ductility in local deformation resulting from spheroidizing of cementite, together with a high *r*-value,[4] which resulted from the rolling texture formed by reducing. The mechanism of the latter is discussed in a separate report.[5]

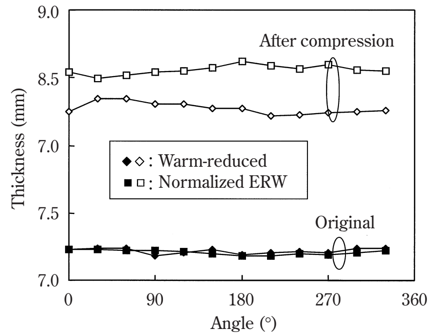
3.2 Cold Workability

3.2.1 Drawing workability

Drawing is performed in order to adjust the dimensional accuracy and surface roughness of high carbon steel tubes, and in many cases, the product is drawn after annealing or normalizing to reduce the cold drawing force. However, with the newly developed tube, it is possible to reduce the force required in cold drawing because spheroidizing of the cementite proceeds in the warm-reduced stage. **Figure 3** shows tensile strength after cold drawing at various reduction-of-area ratios. As the reduction of area increases, tensile strength also increases in both tubes due to work hardening, and as a result, the force which is required in cold drawing increases. However, at all reduction-of-area ratios, the newly developed warm-reduced tube shows lower tensile strength than the normalized ERW tube. From this, it can be estimated that less force is needed in cold drawing with the newly developed tube.

3.2.2 Extrusion workability

One of the processing methods used with ERW tubes is reduction by extrusion, which is performed by inserting a plug inside the tube to control the wall thickness. Without the plug, wall thickness increases during the diameter reduction. Required work force can be decreased if the wall thickness increase is small. **Figure 4** shows the change in wall thickness during reduction by extrusion performed without a plug inside the tube. As a reference sample, a normalized ERW tube of the same chemical composition as the HISTORY tube was used. Because the HISTORY tube showed a smaller increase in wall thickness than the normalized ERW tube, it is considered possible to reduce the necessary working force. This effect is attributed to the relationship with the rolling texture of the HISTORY tube, which is discussed in more detail separately. Namely, the texture of the HISTORY tube is developed under the conditions of contraction in the circumferential direction and elongation in the longitudinal direction. Assuming that texture changes as deformation proceed in the way that facilitate deformation, the tube can easily be worked by extrusion because the deformation proceeds in almost the same manner as that in HISTORY process.

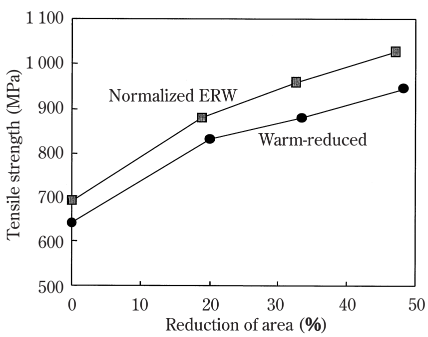


Compression condition: 40.4 mmϕ → 30.7 mmϕ
Steel: SAE15B37H, 0.35%C-0.2%Si-1.4%Mn-B

Fig. 4 Effect of warm-reducing on increasing thickness in compression

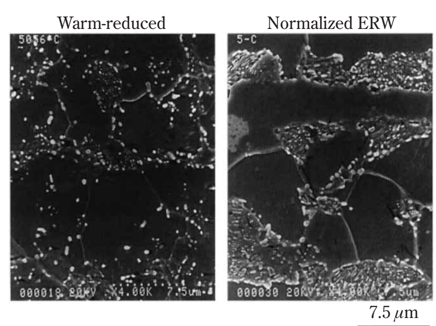
3.3 Tensile Properties after Cold Drawing and Annealing

Photo 2 shows the microstructure after cold drawing and annealing. Lamellar cementite can be observed in parts of the normalized material, but in contrast, spheroidizing is almost complete in the warm-reduced material. **Figure 5** shows the tensile properties when the



Steel: SAE1514, 0.42%C-0.2%C-1.4%Mn

Fig. 3 Tensile strength of warm-reduced high carbon steel tube after cold drawing



Steel: STKM15A, 0.3%C-0.2%Si-0.8%Mn, Etching: Nital

Photo 2 Effect of warm-reducing on microstructure after cold drawing and annealing

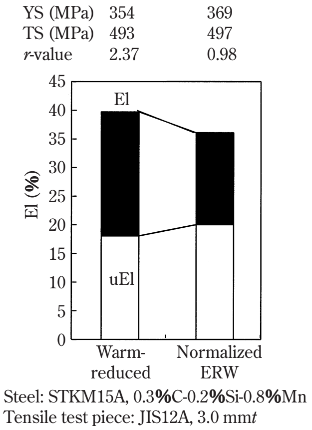


Fig. 5 Effect of warm-reducing on tensile properties after cold drawing and annealing

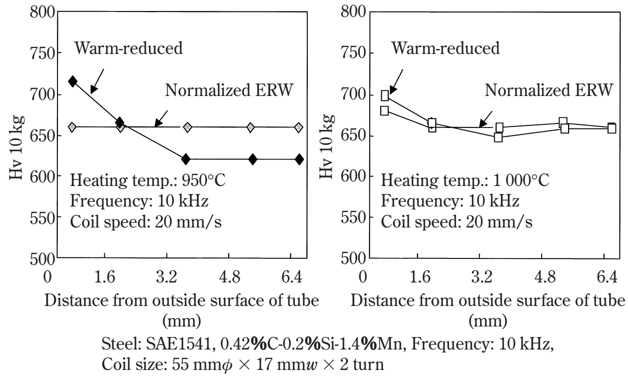


Fig. 6 Effect of heating temperature on induction quenched hardness of warm-reduced steel tube

normalized ERW tube and warm-reduced ERW tube were annealed after cold drawing. The strength of the two tubes is substantially equal, but the elongation of the warm-reduced ERW tube is higher than that of the normalized ERW tube. In particular, the improvement in local elongation El-uEl was remarkable in the warm-reduced tube. Moreover, the *r*-value of the warm-reduced tube is also higher than that of the normalized tube. These differences in tensile properties are the same as the difference before cold drawing, which was shown in Fig. 2. In other words, it is considered that the effects of the texture formation obtained by warm-reduction and spheroidizing of cementite remained even after the cold drawing and annealing in this experiment, and as a result, it was possible to obtain high formability.

4 High Frequency Induction Quenching Property of Newly Developed Steel

Workability is improved by changing the pearlite structure into spheroidized cementite, but on the other hand, it is also known that spheroidizing impairs the high frequency induction quenching property. This is considered to be because the total surface area of the cementite is reduced by spheroidizing, and consequently, it is impossible to complete solute treatment of the cementite in short-time heating such as that in high frequency induction quenching. Therefore, in comparison with steels having a pearlite structure, spheroidized cementite type steels require countermeasures such as use of a higher high frequency induction quenching temperature, etc.

Here, the effect of the heating temperature on the high frequency induction quenching depth of ERW tubes of the newly developed steel and a pearlite structure steel was investigated in order to study the optimum quenching conditions for the new steel. The specimens were 0.42%C-0.2%Si-1.4%Mn steel with dimensions of 40 mmϕ × 6.9 mm$t$. High frequency induction quenching was performed while adjusting the output to obtain surface temperatures of 950°C and 1 000°C, and the change in hardness in the thickness direction was measured. It might be noted that the reference steel with the pearlite structure was a specimen of the newly developed steel which had been normalized at 900°C. The results are shown in **Fig. 6**. With the heating temperature of 950°C, the newly developed steel with the spheroidized cementite structure showed a small high induction quenching depth in comparison with the normalized steel with the pearlite structure. However, it was possible to eliminate the difference between the developed steel tube and normalized tube by increasing the heating temperature by approximately 50°C, to 1 000°C.

5 Available Size Range

Because the newly developed steel tube is manufactured by warm-reduction from a large-diameter mother tube, small-diameter, thick-walled tubes can be produced with relative ease. **Figure 7** shows the currently available size range of the newly developed tubes. In comparison with examples of tubes produced by conventional techniques, it is possible to manufacture tubes with wall-thicknesses approximately 1 mm thicker at all

Thickness (mm)	Outside diameter (mm) 31.8	34.0	38.1	42.7	45.0	48.6	50.8	54.0
10.0								
9.5	Limit of thickness in conventional electric resistance welded steel tubes							
9.0								
8.5							○	○
8.0		○	○	○	○	○	○	○
7.5		○	○	○	○	○	○	○
7.0	○	○	○	○	○	○	○	○
6.5	○	○	○	○	○	○	○	○
6.0	○	○	○	○	○	○	○	○
5.5	○	○	○	○	○	○	○	○
5.0	○	○	○	○	○	○	○	○
4.5	○	○	○	○	○	○	○	○
4.0	○	○	○	○	○	○	○	○

Fig. 7 Available manufacturing size of warm-reduced steel tube

outer diameters.

6 Conclusion

Kawasaki Steel developed the HISTORY process as a next-generation manufacturing technology for electric resistance welded tubes. The following new metallurgical effects were found through this process, which applies warm-reduction to ERW tubes for the first time in the world. The newly developed tubes are considered to be a suitable material for hollow parts such as automobile stabilizers and others.

(1) Spheroidization of cementite can be accelerated by warm-reduction.

(2) High formability high carbon HISTORY steel tubes produced by warm-reduction can reduce the working force in cold drawing.

(3) With high formability high carbon HISTORY steel tubes produced by the warm-reducing process, satisfactory workability can be obtained even after cold drawing and annealing.

(4) Use of the warm-reducing process makes it possible to manufacture small-diameter, thick-walled tubes, which had been difficult with conventional ERW process.

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