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KOBELCO Puts the Customer First with All-in-One Product and Service

Vol. 18 2015 No. 3
What is a Creep Test or Creep Rupture Test?

In both thermal and nuclear power plants as well as chemical plants that operate at high temperature over long periods, heat resistant steels that are high in temperature strength as well as corrosion resistance are required. When evaluating materials, long-term creep strength is an important factor.

Creep is a physical phenomenon in which elastic deformation gradually progresses at high temperatures, weakening the strength of a metallic material even though the stress on the material is small enough not to cause deformation at room temperature.

The international standards of creep and creep rupture tests are outlined in the following:

1. JIS Z 2271:2010, Methods of creep and creep rupture test for metallic materials.
2. ISO 204:2009, Metallic materials — Uniaxial creep testing in tension — Methods of test

A creep test measures the amount of creep strain by converting the amount of elongation measured in a test piece to strain, while a creep rupture test measures the amount of temperature for creep rupture to occur. Figure 1 shows a schematic of a creep test device. It can conduct both creep tests and creep rupture tests. A creep test piece is set up in the device shown in Figure 2. Figures 3 and 4 show the typical creep curves before and after conversion respectively. Tested time, fractured elongation, fractured reduction as well as fractured position were measured by the creep test.

A creep curve generally consists of three stages: I, II and III stages as shown in the curve (Figure 4).

- Stage I: \( E_0 \) - Initial strain, generated right after test stress; also called instantaneous strain.
- Stage II: \( E_0 \approx E \approx \dot{E} \); Stage I, when the creep rate decreases continuously; also called transition creep or primary creep.
- Stage III: \( E 

Whereas the creep curve 1 is standard, the curve 2 appears when test stress or temperature increases to such a high degree that the test piece breaks quickly; in contrast, the curve 3 is seen when low test stress or temperature result in a longer time being required until the test piece ruptures.

When designing plants or equipment, creep tests are performed in those cases when the total amount of strain during operation is specified and the distortion quantity or strain rate in stages I or II become critical. By contrast, in those cases when plants or equipment are used until destruction, creep rupture tests are conducted.

The third Shinyokai established in China: based on a relationship of trust

Dear KWT readers! Thank you very much for your continuous patronage of Kobe Steel products. Although we faced and were influenced by many challenges in the economic environment this year, such as falling crude oil prices, unreasonable weather in the North America and Thailand, the financial problems in Greece, and the downturn in economic growth in China, the biggest market in the world, our activities remained stable under these circumstances, thanks to the kind understanding and support of KWT readers. I am especially grateful to the people in our local distributors and agents.

Presently Kobe Steel has been establishing a new mid-term business plan (for 2016). In the Welding Business, which aims to remain “the most reliable enterprise for total welding solutions in the world,” we have been studying action plans and setting up targets that meet the needs of the diverse regions we operate in. I believe what is most important in order to provide our customers with excellent products and services is to strengthen our ability to respond to inevitable changes in the business environment and to establish structures strong enough to survive those changes. On the other hand, there is one thing that never changes even if the environment changes to a considerable extent. It is our vision to value the long-time and trusting relationships with our end-users, local distributors and agents. I promise to give more emphasis to this in the new mid-term plan.

This year saw excellent examples of how we build a relationship based on trust. In June, the Kobe Steel group in China was formed and named “China Shin-yo-kai,” it is the third Shinyokai after the ones in Japan and Thailand. The Shinyokai, established in Japan in 1952, has contributed to Japanese welding societies through the introduction of welding consumables as well as welding technologies. The relationship built on trust by members of the Shinyokai has been a driving force of sales and marketing. The vision of the Shinyokai is represented by the three colors in its logo: violet for tradition, red for innovation, and gold for prosperity. We would like to extend those colors in the years to come. And we would like to deepen our relationship of trust so that we might create the fourth and fifth Shiyokai.

In 2015, we have displayed our latest welding consumables and robotic welding systems in China, Russia, Brazil, the USA and India, while at the same time enhancing the friendships we have cultivated among many KWT readers. In April 2016, the welding exhibition will be held in Osaka, Japan, and we look forward to seeing all of you there. Although there are only a few months left in this year, we wish you the best of luck for the fruitful year.
1 Preface

Today, 60% of electric power worldwide is generated from fossil-fuels such as coal, petroleum, and natural gas as shown in Figure 1, and it is forecast that the similar ratio will be maintained even after 2020. Because the generation of thermal power from fossil fuels such as coal, petroleum, and natural gas requires repeated starts and stops in response to electric power demand. The typical high Cr ferritic heat resistant steel is ASTM T91 and P91 steel (modified 9Cr-1Mo steel, hereinafter called T91/P91), which has been applied in large numbers of thermal power boilers.

Kobe Steel has developed and marketed welding consumables for T91/P91 steel such as the 9Cb series, which has been applied in thermal power plants in Japan for decades, and the B9 series, which matches with AWS specifications. In this issue, we discuss some recent trends in international standards as well as the covered arc electrodes, TRUSTARC™ CM-95B91 and TRUSTARC™ CM-96B91, both of which have newly been developed to meet AWS A5.5: 2014 specifications for T91/P91 steel.

2 Recent trends in international standards

International standards related to welding consumables for T91/P91 steels have significantly changed in the last ten years. Key changes relate to the requirements for Mn+Ni content and the post weld heat treatment (PWHT) temperatures that are closely related to the Mn+Ni content. Tables 1 and 3 show how the standards have been modified by the American Standard of Mechanical Engineers (ASME, the manufacturing standard), while Table 2 shows the AWS standards (the welding consumable standard) and Table 4, those of the Electric Power Research Institute (EPRI, the industry organization).

For T91/P91 steel welded joints, PWHT is indispensable in order to reduce residual stress. However, the creep rupture strength and/or notch toughness of those weld metals can become unstable if the PWHT temperature exceeds their Ac1 transformation temperature (Ac1), because fresh martensite* microstructure can begin to form.

Because its thermal expansion coefficient is smaller than austenitic heat resistant steel, high Cr ferritic heat-resistant steel is more useful in thermal power generation, which requires repeated starts and stops in response to electric power demand. The typical high Cr ferritic heat resistant steel is ASTM T91 and P91 steel (modified 9Cr-1Mo steel, hereinafter called T91/P91), which has been applied in large numbers of thermal power boilers.

Japanese laws and regulations specify a maximum PWHT temperature of 760°C for T91/P91 steels. Kobe Steel has frequently discussed those conditions, and the round robin test for T91/P91 steels has finally been adopted in the International Institute of Welding (IW) in 2013. We were the only welding consumable manufacturer in the world to participate in it.

Table 1: ASME B31.1 trends

<table>
<thead>
<tr>
<th>Year</th>
<th>Mn+Ni content (mass %)</th>
<th>Upper limit of PWHT temperature of production (°C)</th>
<th>Reference (Year of revision)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2008</td>
<td>Not regulated</td>
<td>760</td>
<td>Table 13-2 P-No. 18</td>
</tr>
<tr>
<td>2009</td>
<td>Not regulated</td>
<td>770</td>
<td>Table 13-2 P-No. 18</td>
</tr>
<tr>
<td>2010</td>
<td>1.0 or 1.50</td>
<td>775</td>
<td>Table 13-2 P-No. 18</td>
</tr>
</tbody>
</table>

Note: * B9 SAW, SAW, GTAW and FCAW

Table 2: AWS B9/B91 trends

<table>
<thead>
<tr>
<th>Year</th>
<th>Mn+Ni content in deposited metal (mass %)</th>
<th>Upper limit of PWHT temperature at classification (°C)</th>
<th>Reference (Year of revision)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2008</td>
<td>Not regulated</td>
<td>760</td>
<td>Table 13-2 P-No. 18</td>
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<tr>
<td>2009</td>
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<tr>
<td>2010</td>
<td>1.0 or 1.50</td>
<td>775</td>
<td>Table 13-2 P-No. 18</td>
</tr>
</tbody>
</table>

Table 3: ASME trends (other specifications)

<table>
<thead>
<tr>
<th>Year</th>
<th>Upper limit of Mn+Ni content (mass %)</th>
<th>Upper limit of PWHT temperature for production (°C)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>2012</td>
<td>1.0 ∗</td>
<td>Code Case 2920-B-89 For repairing cast products</td>
<td></td>
</tr>
<tr>
<td>2013</td>
<td>1.2 ∗</td>
<td>Sect. 1, PW 5.4, B9 For high-pressure resistant members</td>
<td></td>
</tr>
</tbody>
</table>

Table 4: Trends in published EPRI reports

<table>
<thead>
<tr>
<th>Year</th>
<th>Mn+Ni content (mass %)</th>
<th>Upper limit of PWHT temperature for production (°C)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>2001</td>
<td>1.00</td>
<td>770</td>
<td>Report No. 1023199 SAW, SAW, FCAW, FCAW, GTAW, GTAW</td>
</tr>
<tr>
<td>2014</td>
<td>1.00</td>
<td>770</td>
<td>Report No. 3002001472 Proposals of optimizing chemical compositions for PWHT</td>
</tr>
<tr>
<td>2015</td>
<td>1.00</td>
<td>770</td>
<td>Report No. 3002001472 Proposals of optimizing chemical compositions for PWHT</td>
</tr>
</tbody>
</table>

Note: * Sum of Mn and Ni specified upper limit is 0.70
1 Upper limit of tempering temperature is 700
2 Revision of Report No. 1023199 (2011) in discussion.
3 Estimated figures due to ∗∗, report above under discussion.

3.1 Features of CM-95B91 and CM-96B91

These covered electrodes were designed to achieve the following three requirements:

1. No appearance of fresh martensite microstructure, even at 760°C or higher PWHT temperature.
2. Prevention of residual fresh martensite (which degrades long term creep rupture strength) remaining in the deposited metal.
3. Long-term creep rupture strength of deposited metal that is equal or better than T91/P91 steel.

For the reasons discussed above, the upper limits on Mn+Ni content and PWHT temperature have been continuously revised in all the standards. What they all have in common is to prevent the formation of fresh martensite.

The latest versions of typical international standards specify as follows:

- ASME (B31.1: 2014) 1.2 %; 2. A3 or Ac1
- AWS (A5.5: 2014) 1.40 %; 2. 775 °C
- EPRI report (No. 2023199: 2011) 1. 1.00 %; 2. 770 °C

One may ask how A3: is measured internationally. ASTM A1033-04 specifies a method for measuring the transformation point of carbon steel and low alloy steel. However, no international standard specifies test conditions such as measuring method or rates of increasing or decreasing temperatures in order to measure A3: for high Cr ferritic heat resistant steels.

Kobe Steel has frequently discussed those conditions, and the round robin test for T91/P91 steels has finally been adopted in the International Institute of Welding (IW) in 2013. We were the only welding consumable manufacturer in the world to participate in it.
CM-95B91 and CM-96B91 are designed to maintain the lower limit of PWHT temperature as specified in AWS, that is, 745 °C (760-15). Table 5 shows the typical chemical compositions of their deposited metals as well as the latest AWS A5.5: 2014 specifications.

### 3.1 Optimum addition of Mn and Ni

Because a large amount of Cr (a ferrite forming element) is contained in welding consumables for T91/P91 steels, δ ferrite, which lowers long-term creep rupture strength, tends to remain in the weld metal. Therefore, by adding Mn+Ni, an effective chemical composition is created that prevents δ ferrite from remaining in the weld metal\(^2\). On the other hand, as seen in Figure 2, the addition of Mn+Ni content lowers Ac1, leading to a higher risk of fresh martensite formation.

Figure 2: Relationship between Mn+Ni and Ac1 of weld metal for high Cr ferritic steel

For these reasons, CM-95B91 and CM-96B91 are designed to contain the minimum amount of Ni necessary to lower the residual δ ferrite, and enough Mn so that the total Mn+Ni content amounts to 1.0 %.

Figure 3 indicates the relationship between Mn and Ni and creep rupture time of deposited metal for T91/P91 steel. It can be seen that Mn is less influential than Ni on creep rupture time, which becomes longer as Ni content is reduced. It is believed that longer creep rupture life is related to the delay of lath microstructure recovery.

### 3.1.2 CNB (Cr equivalent − Ni equivalent balance)

EPR1 Report No. 1023199 states that T91/P91 steel products shall have a martensite single-phase structure with no δ ferrite in order to secure creep rupture strength and proposes an index by the following equation:\(^3\):

\[
\text{CNB = (Cr+6Ni+4Mo+1.5Cr+11V+5Nb+12Al) - (40C+30N+4Ni+2Mn+1Cu)}
\]

\(\leq 10 \text{ (mass %)}\)

CM-95B91 and CM-96B91 are also designed to comply with the above CNB index, so that long-term creep rupture strength can be maintained by reducing residual δ ferrite in deposited metal. Furthermore, in addition to Mn and Ni, Co is also added, which also reduces residual δ ferrite in deposited metal. Figure 4 shows the relationship between the Mn+Ni and Co content and Ac1 (measured value) and \(A_3\) (calculated by Thermo-calc) in a deposited metal of T91/P91 steel. It can be seen that Co does not lower \(A_3\) even if it is added in with Mn and Ni.

### 3.2 Mechanical properties

The relationship between tensile properties and heat treatment parameter, commonly referred to as the Larson-Miller Parameter (LMP), on CM-95B91 deposited metal is shown in Figure 5 and the relationship between impact properties and LMP, in Figure 6, respectively.

Figure 6: Relationship between impact properties and LMP

It is understood that the tensile strength of CM-95B91 deposited metal is equal to or more than that of T91/P91 steel when PWHT ranges from LMP (\(\leq 10^{-3}\)) to LMP (\(\leq 10^{-5}\)): 20.6 (743 °C \(\times 2.1\) hr) to LMP (\(\leq 10^{-5}\)): 22.0 (779 °C \(\times 8.0\) hr). Although there is no formal requirement for the impact properties, we have used \(\xi_{VE20°C}=238 J\) average as an example for comparison. If PWHT is equal to or more than 760 °C \(\times 2.7\) hr (LMP \(\times 10^{-3}\): 21.1), it is considered that CM-95B91 deposited metal can secure the practical level of impact properties.
3.3 Creep rupture property

Figures 7 and 8 show the creep rupture properties of CM-95B91 deposited metal at the test temperatures of 650°C and 600°C, respectively.

Figure 7: Creep rupture property at 650°C

![Chart showing creep rupture property at 650°C](image)

The test result of CM-95B91 deposited metal at 650°C indicates its creep rupture strength is higher than that of T91/P91 steel. The long-term creep rupture test at 600°C, based on an assumption of rupture time of about 40,000 hours (about 4.5 years) as shown in Figure 8 in progress.

![Chart showing creep rupture property at 600°C](image)

4 Notes on usage

A high Cr ferritic heat resistant steel weld metal is more susceptible to delayed cracking due to its self-hardening properties than 1.25Cr-0.5Mo or 2.25Cr-1Mo heat resistant steel weld metal. Therefore, the following notes on usage are important:

1. It is necessary to maintain preheating and interpass temperatures between 250 and 350°C for preventing delayed cracks.
2. It is also essential to re-heat electrodes before use for one hour at 350-400°C to satisfy the H4 (AWS diffusable hydrogen level) requirement.
3. Excessively high welding currents and speeds have to be avoided to prevent hot cracks as well. Kobe Steel’s welding consumables for high Cr ferritic heat resistant steels are designed to contain low amounts of P and S to prevent hot cracks. However, the deposited metal of T91/P91 steel has a wider solid-liquid coexisting temperature range than that of 1.25Cr-0.5Mo or 2.25Cr-1Mo heat resistant steel, resulting in higher susceptibility for hot cracks.

5 Postscript

This article has discussed some recent trends in international standards related to T91/P91 heat resistant steels for fossil-fuel thermal power generation, as well as the features of CM-95B91 and CM-96B91, covered arc consumables in order not to allow those to become obsolete, development of international standards of welding consumables in order not to allow those to become unrealistic for welding consumable manufacturers.

References

1. The Institute of Energy Economics, Japan - Asia/World Energy Outlook 2014
4. EPRI 1023199: Guidelines and Specifications for High-Reliability Fossil Power Plants (2011)
6. National Institute for Materials Science (NIMS) Creep Data Sheet, No. 43A
FABTECH Mexico 2015, the leading metal manufacturing event in Mexico was held at Cintermex in Monterrey, Mexico, from May 5 to 7, 2015.

Monterrey, the capital of the northeastern state of Nuevo Leon with a population of about 4 million, is Mexico’s third largest city after Mexico City and Guadalajara. As one of the main cities for business and industry, it has large numbers of foreign companies operating there as well.

The exhibition attracted 530 exhibitors and 11,000 visitors from all over the Americas. It was reported later that the event had become the largest manufacturing exhibition in Central and South America with the highest-ever number of exhibitors and visitors.

FABTECH Mexico is a co-located event, with AWS Weldmex (welding and cutting), METALFORM Mexico (industrial machines) and COATech (painting) sharing the exhibition space.

At AWS Weldmex, about 150 companies, from local distributors to world-renowned welding manufacturers, displayed their products. Kobelco Welding of America (KWAI) took part, representing the Kobelco group for the first time. Displayed were panels of our main products: flux cored wires for mild steel as well as stainless steels (such as carmakers) to set up manufacturing operations. In addition, energy-related businesses are expected to expand due to liberalization of Mexico’s oil sector.

Under the motto that we remain “the most reliable enterprise for total welding solutions in the world” we, the Kobelco group, will make the utmost effort to provide Latin American customers with our high-quality welding consumables as well as to establish an organizational structure for supplying the level of technical services expected by customers for their quality-oriented projects in Mexico.

The annually held FABTECH Mexico rotates each year between Monterrey and Mexico City. We are going to set up our booth again and look forward to seeing you there in 2016.

Entrance of FABTECH Mexico 2015

Kobelco group announces new slogan at Beijing Essen 2015

The 20th Beijing Essen Welding & Cutting Fair (BEW) (sponsored by Chinese Mechanical Engineering Society, among others) was held at Shanghai New International Expo Center on June 16 – 19, 2015. BEW is the largest and most influential welding exhibition in China and attracted 989 exhibitors from 28 countries this year.

While the news media has been reporting a drop in the Chinese economy, China is still the biggest market for welding consumables in the world, a fiercely competitive environment, not only for international manufacturers but domestic Chinese ones as well. Against this backdrop, the Kobelco Group participated in this year’s exhibition in order to help the Kobelco brand and presence penetrate more deeply into the Chinese market.

We displayed some of our latest technologies, including a live demonstration of the ARCMAN™ robot welding system with FAMILIARC™ DW-110EV - a flux cored wire (FCW) for vertical upward welding that has been exclusively developed for the Chinese market. Demonstrations of both PREMIARC™ DW-309LP (FCW for stainless steel in all positions) and FAMILIARC™ MG-50CH (a solid wire for large current welding of construction machinery) were also performed. In addition, the booth panels and displays of welding consumables and bead samples highlighted our offerings for such industries as shipbuilding, offshore structures, automobile, construction machinery and chemical vessels.

All of the displays attracted the interest of many visitors from all over the world as well as from China.

By the time the fair ended, I was convinced that in the globally-significant Chinese market, it is essential that we establish our position as a reliable solution partner who can propose outstanding welding processes, systems and consumables. I also felt that our three local companies - Kobe Welding of Tangshan Co., Ltd.; Kobe Welding of Qingdao Co., Ltd.; and Kobe Welding of Shanghai Co., Ltd. - together with Kobe Steel, must increase their presence in the Chinese market and establish a position as the world’s most reliable company for welding solutions as soon as possible.

Kobelco booth entrance with new slogan

As shown in the above photo, the entrance to the Kobelco booth featured a new slogan in Chinese: “Technology develops Kobe Steel and Quality (Products) create the future.”

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