Comparative Study of Cooling Curves with JIS Silver Specimens and Alloy 600 Specimens in Relation to Additive Effectiveness

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Quenching-oil cooling curves obtained using a silver specimen (Japanese Industrial Standard K 2242) indicate three stages of cooling: vapor blanket, boiling, and convection. The temperatures at which the vapor blanket stage transfers to the boiling stage and the boiling stage transfers to the convection stage are referred to as the characteristic temperature (CT) and the convection-stage starting temperature (CSST), respectively. As the amounts of CT-improving additives are increased in increments of 1, 2, 3, 6, 8, 10, and 12%, the CTs become higher, as clearly shown in the cooling curves obtained using a silver specimen. Likewise, as the amounts of CSST-improving additives are increased from 1 to 2 to 3%, the CSSTs become lower. These tendencies are similarly observed when using an Alloy 600 specimen, and both additives effectively improve cooling performance. However, in the case of 6, 8, 10, and 12% CT-improving additions, the differences among the additive concentrations are more pronounced in cooling curves obtained using the silver specimen than in those obtained using the Alloy 600 specimen. This can be attributed to the greater temperature sensitivity of the silver specimen thermocouple. In field quenching operations, such phenomena as insufficient hardness, inverse quench hardening, and unstable distortion can be remedied by additive treating. However, one must know what type of additive and how much to use. To this end, cooling curve measurement using silver specimens is useful.

Keywords

cooling curves, cooling rates, hardenability, quench testing, quenching

1. Introduction

IN Japan it is common practice to measure cooling curves according to the Japanese Industrial Standard (JIS) method (Ref 1) when selecting a suitable oil for steel quenching. Such curves are also used to solve problems such as insufficient hardness, inverse quench hardening (Ref 2), and unstable distortion in field quenching operations. A number of other methods are available for the measurement of the cooling power of quenching oils. Alloy 600 is widely used as a test probe and is being proposed for the ISO standard method (Ref 3). This paper discusses the salient features of both methods from the viewpoint of additive effectiveness.

2. Silver Specimen Cooling Curves and Additive Effectiveness

It is well known that measurement of the cooling curves of quenching oils using a silver specimen indicates three stages of cooling: the vapor blanket or vapor film stage, the boiling stage, and the convection stage. The temperature at which the vapor blanket stage transfers to the boiling stage is called the characteristic temperature (CT). The temperature at which the boiling stage transfers to the convection stage is called the convection-stage starting temperature (CSST) (Ref 4) (Fig. 1).

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Usually, neat quenching oils produce a long vapor blanket stage and a low CT. If a CT improver (P_a) is added to the oil, the characteristic temperature becomes higher and the vapor blanket stage shorter. If a CSST improver (P_b) is added to the oil, the convection-stage starting temperature becomes lower and the cooling rate at the lower part of the curve becomes higher. Accordingly, when these additives are used together, both effects are obtained; that is, the vapor blanket stage becomes shorter with a higher CT, and the CSST becomes lower, with a higher cooling rate at the lower part of the curve (Fig. 2). In steel quenching, when sufficient hardness is not obtained, the cooling power can be improved through incorporation of both additives.

Base oils for general martempering oils are short in the vapor blanket stage and high in CT. Addition of a CSST improver, P_b, to the base oils can make them good martempering oils without changing the CT (Fig. 3). Martempering oils are effective in reducing distortion, but are sometimes insufficient in quench hardness. Addition of the CSST improver is an effective way to meet required hardness and control distortion.

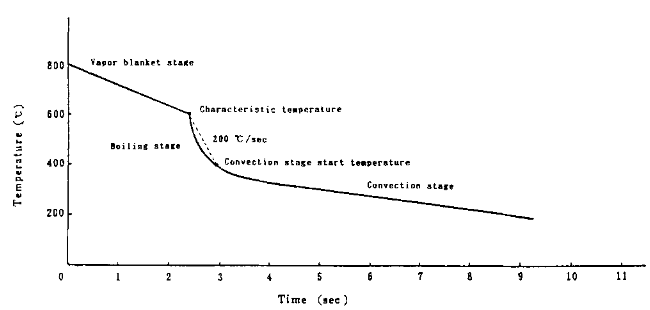

Fig. 1 Vapor blanket, boiling, and convection stages, CT, and CSST on a cooling curve obtained using a silver specimen

3. Test Probes

3.1 *JIS Silver Specimen*

This specimen is stipulated in JIS K 2242 (Ref 1) and consists of a silver rod body for the test probe and a silver pipe/alumel wire thermocouple (Fig. 4). The silver must be at least 99.99% pure. The silver rod body is 10 mm in diameter and 30 mm long and is equipped with a thermocouple at its surface in the middle of the longitude. The silver rod, attached to a supporting steel rod, is heated to 810 °C, kept at temperature for 2 to 3 min, and then plunged into 250 mL of stationary sample oil to record the cooling curve. After each use, the surface of the silver rod must be ground slightly with emery paper E No. 500.

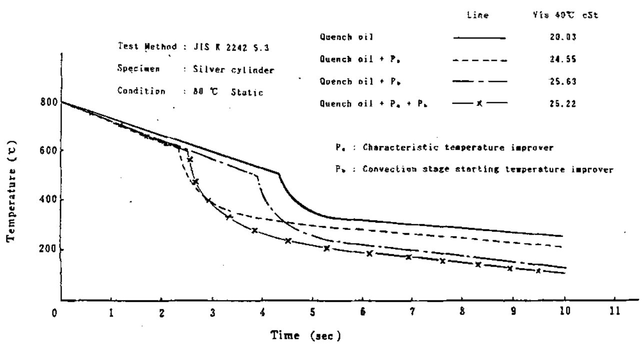

Fig. 2 Cooling curves obtained using a silver specimen that indicate the effectiveness of additives P_a and P_b in a quenching oil

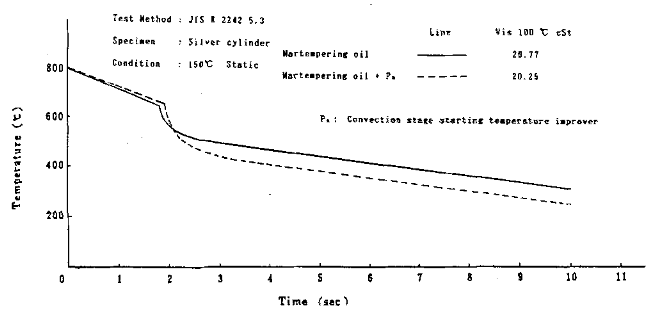

Fig. 3 Cooling curves obtained using a silver specimen that indicate the effectiveness of additive P_b in a martempering oil

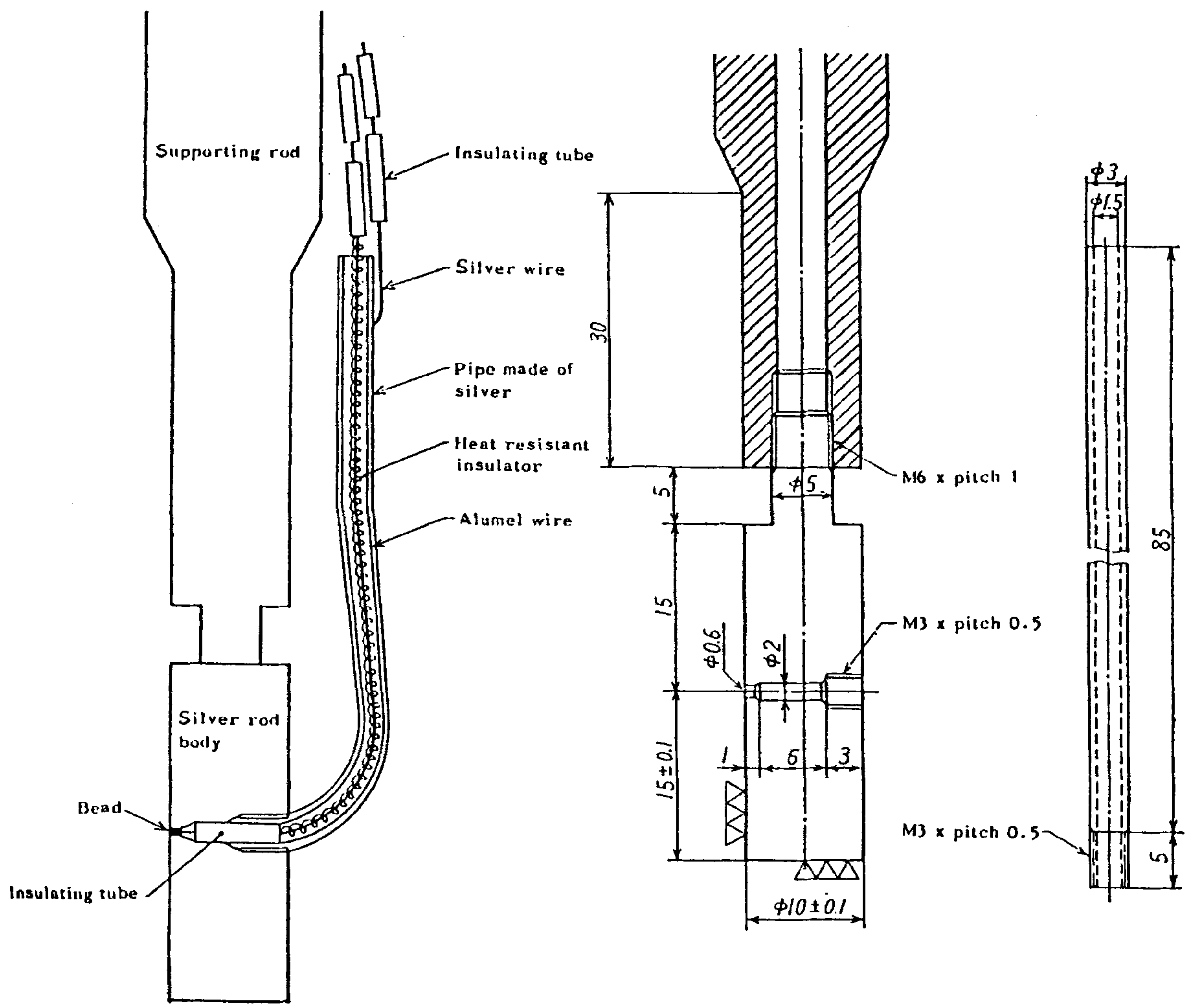

Fig. 4 Silver specimen for measuring JIS K 2242 cooling curves. Source: Ref 1

3.2 *Alloy 600 Specimen*

This specimen was adopted first by Wolfson Heat Treatment (U.K.) and then by the International Federation for Heat Treatment and Surface Engineering (IFHT). It is now being proposed for the ISO standard method (Ref 3). The method uses an Inconel (Inco Alloys International, Inc., Huntington, WV) Alloy 600 specimen for the test probe with an alumel/chromel thermocouple embedded at the geometrical center (Fig. 5). The specimen is heated to 850 °C and placed in 2000 mL of stationary sample oil, recording the cooling curve and the rate/temperature curve. The surface of the specimen is then washed with solvent and wiped to remove the oil.

4. Measurement of Cooling Curves

A comparison was made of the cooling curves of additive-incorporated quenching oils obtained using a silver specimen and an Alloy 600 specimen. Figure 6 shows cooling curves obtained using a silver specimen for a neat quenching oil and for oils containing the CT additive, P_a, at concentrations of 1, 2, 3, 6, 8, 10, and 12%. As the amounts of P_a are increased, the CTs become higher and the vapor blanket stages shorter.

Figure 7 shows the results using an Alloy 600 specimen; the tendencies are similar. However, in the case of 6, 8, 10, and 12% P_a additive incorporations, the differences among the additive concentrations are not as clear compared with the case using the silver specimen. This is obviously due to the higher sensitivity of the silver specimen. Figures 8 and 9 show the cooling curves for a neat quenching oil and for oils incorporated with the CSST additive, P_b, at concentrations of 1, 2, and 3%. For both specimens, as the amounts of P_b are increased the CSSTs become lower and the cooling power in the lower part of the curve is improved. Also, however, the differences among the additive concentrations are more clearly observed for the silver specimen than for the Alloy 600 specimen. This can be attributed to the different positioning of the thermocouples. The silver specimen, with the thermocouple installed at the surface, is more temperature sensitive than the Alloy 600 specimen.

Finally, cooling curves for new and used bright quenching oil S-1050 obtained using silver and Alloy 600 specimens are

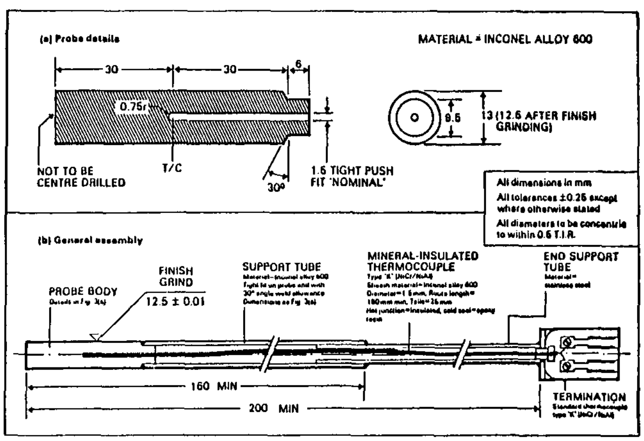

Fig. 5 Alloy 600 specimen for measuring IFHT cooling curves. Source: Ref 3

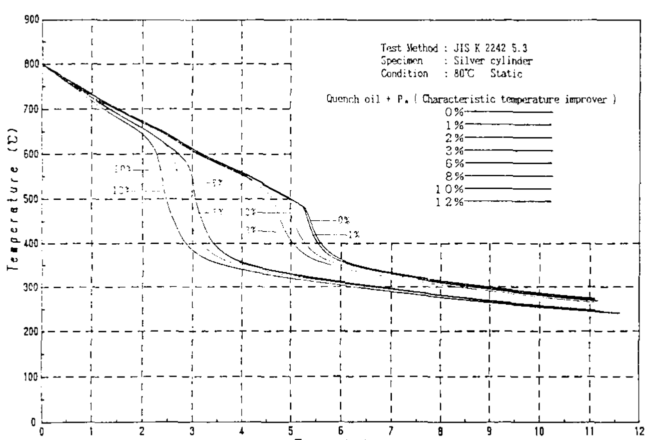

Fig. 6 Cooling curves obtained using a silver specimen for quenching oils with increasing dosages of CT additive P_a

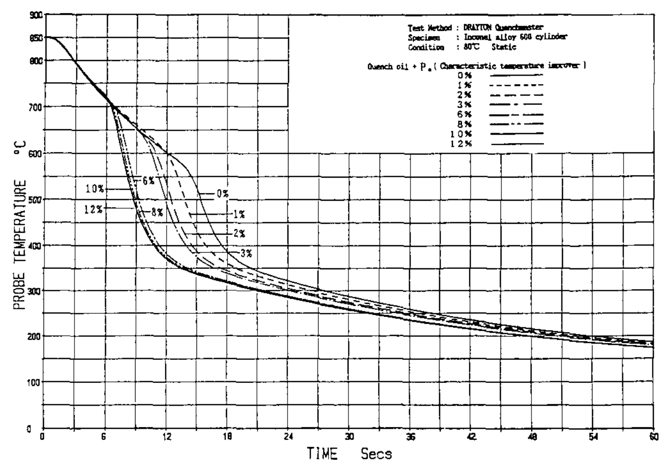

Fig. 7 Cooling curves obtained using an Alloy 600 specimen for quenching oils with increasing dosages of CT additive P_a

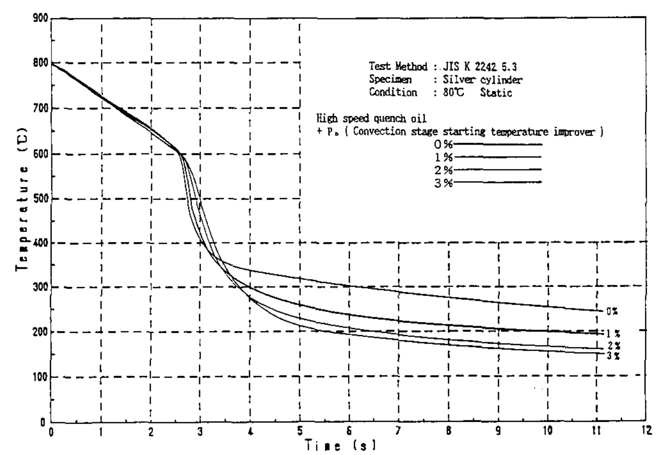

Fig. 8 Cooling curves obtained using a silver specimen for high-speed quenching oils with increasing dosages of CSST additive P_b

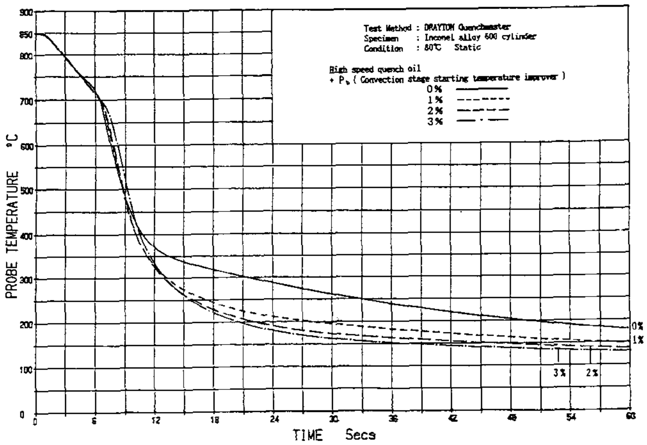

Fig. 9 Cooling curves obtained using an Alloy 600 specimen for high-speed quenching oils with increasing dosages of CSST additive P_b

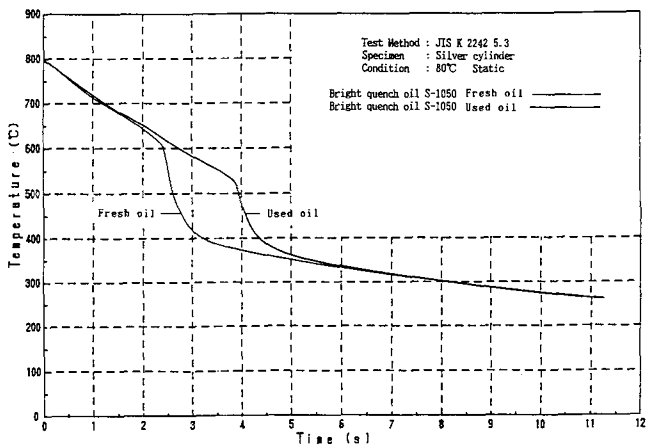

Fig. 10 Cooling curves obtained using a silver specimen for fresh and used samples of bright quenching oil S-1050

shown in Fig. 10 and 11, respectively. Again, the tendencies are the same, but the silver specimen shows differences more clearly than the Alloy 600 specimen.

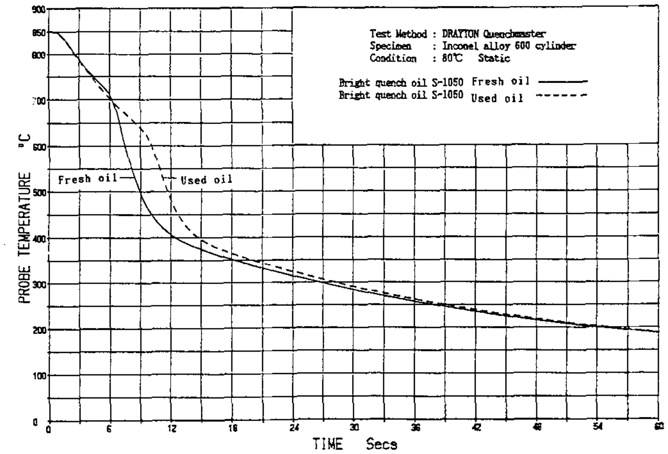

Fig. 11 Cooling curves obtained using an Alloy 600 specimen for fresh and used samples of bright quenching oil S-1050

5. Conclusions

The investigation has proved that the JIS silver specimen can respond to changes in the cooling curves of quenching oils better than the Alloy 600 specimen. Cooling curves vary according to the type, combination, and concentration of additives. Subtle differences in cooling curves can be detected by silver specimens. Insufficient hardness and unstable distortion of workpieces are closely related to the cooling performance of the quenching oil. To remedy these problems, one must know what type of additive and how much to use. To this end, cooling curve measurement using silver specimens is useful.

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