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

I. Tamura, K. Fukuhara, and S. Asada

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).

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](image-url)
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