IMPACT OF COPPER ON THE TEMPERING OF NICKEL-CHROMIUM STEELS

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Abstract

The tempering behaviour of some low-alloy nickel-chromium steels with different percentage of copper was studied through hardness measurements. The quenched as well as normalised steels were tempered at different temperatures for varying periods of time and a comparative study of their precipitation behaviour was made. Tempering at 500°C led to appreciable secondary hardening that could be understood as essentially due to sub-microscopic precipitation of copper.

Introduction

COPPER has been in use as an alloying element in steel for the past many decades. Smith and Palmer[1] demonstrated as early as in 1933 that considerable strengthening can be obtained in copper steels by aging them in the quenched or normalized condition. Following the report in 1934 of Gregg and Daniloff[2] and the findings later of many other workers[3-5] on the precipitation hardening effects of copper in steels, Kenneford[6] showed that copper delayed softening in plain-carbon steels during tempering. Hornpogen and Glean[7] studied the precipitation behaviour of iron-copper alloys and concluded a decade ago that copper precipitated as spherical particles in these alloys in the temperature range 400–500° C. Kenneford and Oxlee[8] have also reported precipitation of copper in plain-carbon steels in the range 400–500° C. More recently Wilson[9] investigated the precipitation hardening effects of copper in ferrous alloys containing nickel and chromium, while Tamura *et al.*[10] studied the effect of copper on molybdenum steels. Cox[11] has been the latest to confirm the precipitation of copper in steels around 500° C on the basis of a transmission electron-microscopic study.

Though considerable work has been done on the role of copper in plain-carbon steels, there has been no detailed study on copper-bearing alloy steels. Even the work by Wilson[9] referred to above was limited to carbon-free (maraging) steels containing nickel and chromium. It was therefore proposed in our laboratories to extend this precipitation work to some alloy steels.

The work reported here concerns Fe-C-Ni-Cr steels containing copper. Low-alloy-chromium steels are known[12] not to exhibit secondary hardening though chromium carbide precipitates during tempering, obviously because the carbides in the steels do not delay the softening process on tempering. As an alloying element that precipitates at about the same range of temperature (400–600° C) as chromium carbide, copper may well be expected to stabilize chromium carbide and thus contribute to some secondary hardening in steels containing chromium. As copper is retained in solid solution, even if the steel is air-cooled from the austenitic range,[3] tempering of even normalized steels may be expected to bring about precipitation of copper. In the present work, therefore, apart from the quenched steels, normalized (air-cooled) specimens were also tempered at different temperatures. Some nickel was added to the steels under study since the former is known to reduce hot shortness in copper-bearing steels[6].

Experimental Procedure

The steels of the chemical compositions shown in Table I were made in a high frequency induction furnace. The steels were hot forged to 1/4" thick plates. Those containing 1·63% and 2·90% copper forged quite well, while those with 3·54% copper showed slight cracking. Specimens of $1'' \times \frac{1}{2}'' \times \frac{1}{4}''$ size were made from the forged plates.

The specimens were subjected to the following heat treatments in salt bath furnaces:

1. Austenitization at 950° C for 1 hour and quenching in brine at room temperature.
2. Austenitization at 950° C for 1 hour and normalizing to room temperature.

The quenched as well as normalized steels were tempered in the range 300–600° C at intervals of 100° C. The tempering time varied in each case from 15 minutes to 100 hours.

Vicker hardness measurements were made on all specimens with 30 kg load before and after tempering treatment. In each case the average of at least five measurements was recorded.

Table I

Compositions of steels under study
(The values are in weight percentages and as per chemical analysis)

Steels	C	Ni	Cr	Cu
A	0·27	1·48	1·00	1·63
B	0·31	1·58	1·07	2·90
C	0·42	1·58	1·07	3·54

Experimental Results

(I) *Tempering of Quenched Steels.*—Figures 1, 2 and 3 show the variation in hardness of quenched steels with tempering time at 400 and 500° C. The as-quenched hardness of steel C was very high (nearly 600 V.H.N.) as compared to steels A and B (440 and 460 V.H.N.) and could be understood in terms of its higher carbon content[13].

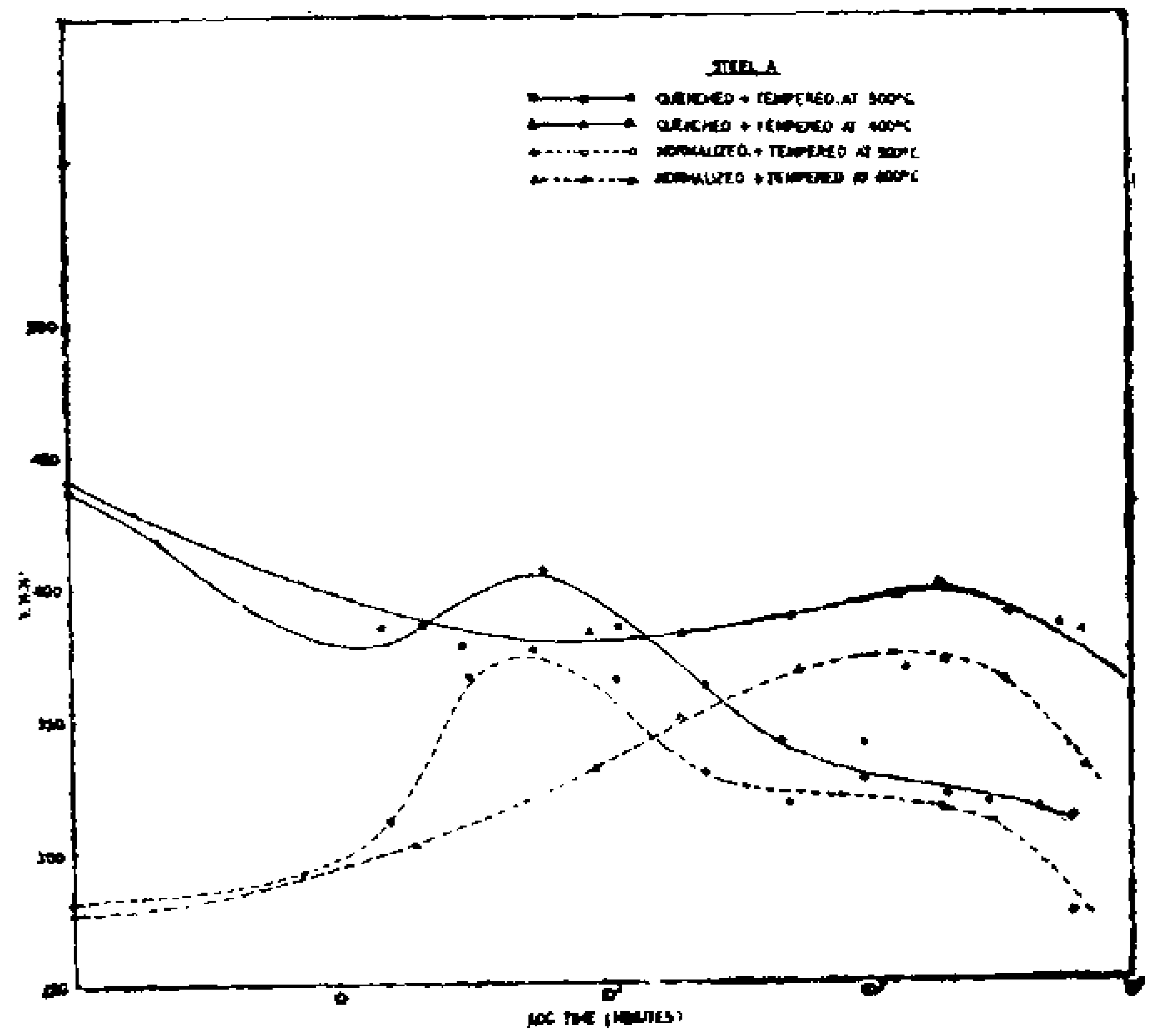

Fig. 1 Hardness curves of steel A (0·27% C, 1·48% Ni, 1·00% Cr and 1·63% Cu) for different tempering temperatures.

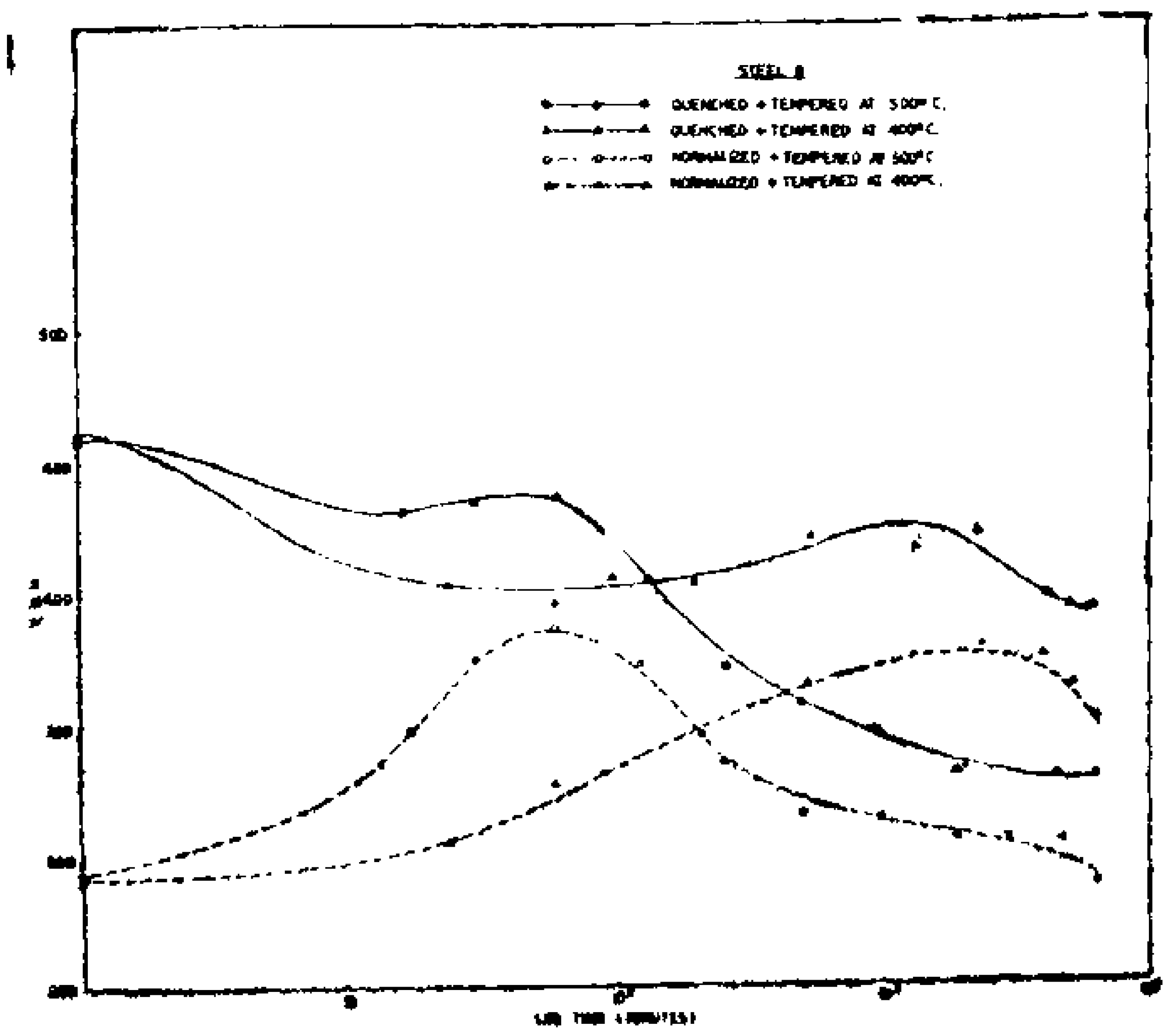

Fig. 2. Hardness curves of steel B (0·31% C, 1·58% Ni, 1·07% Cr and 2·90% Cu) for different tempering temperatures.

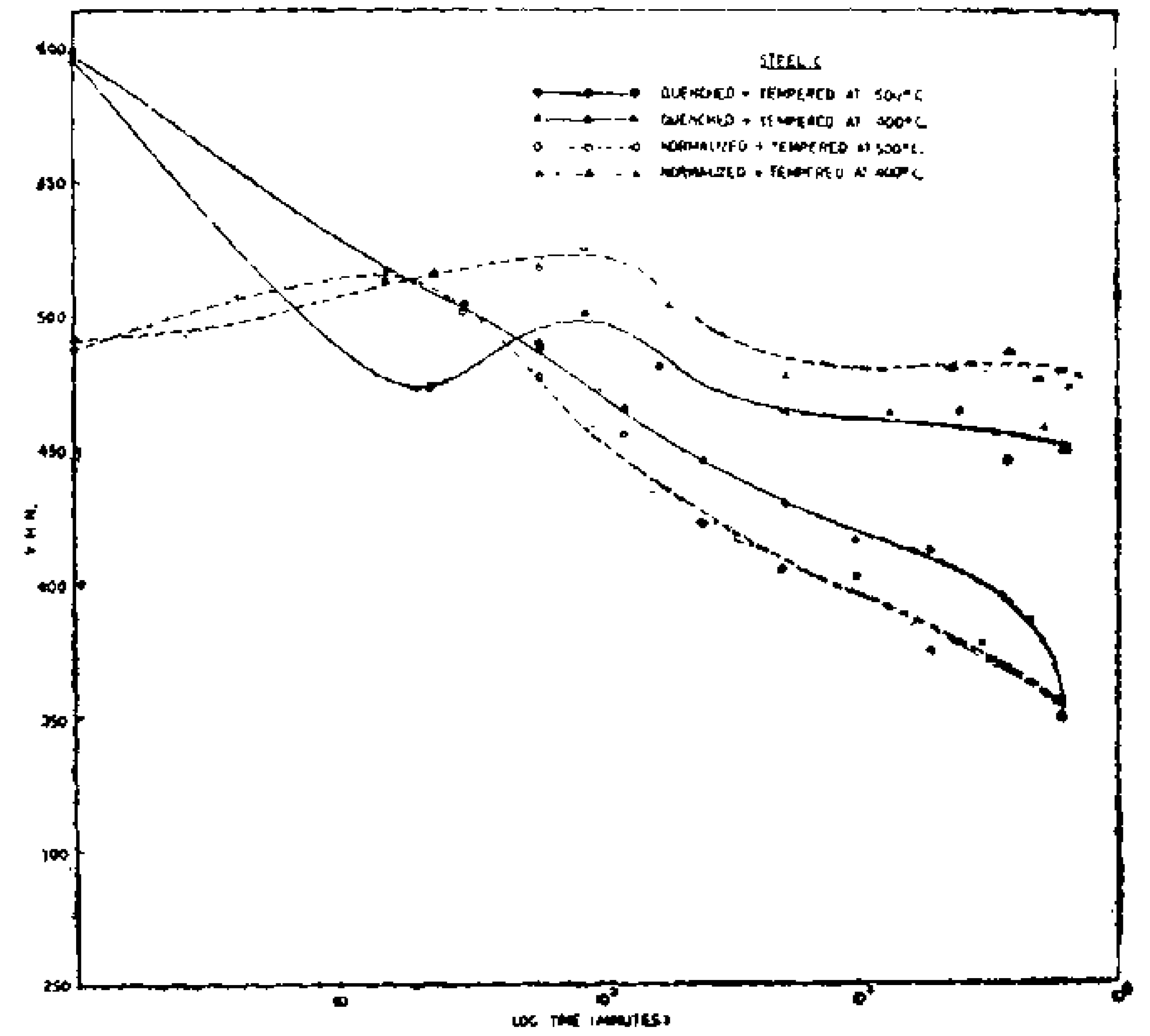

Fig. 3. Hardness curves of steel C (0·42% C, 1·58% Ni, 1·07% Cr and 3·54% Cu) for different tempering temperatures.

Tempering of steels at 300° C showed an initial drop in hardness then practically no change and finally an increase on prolonged aging. Any appreciable increase in hardness could be observed only after 100 hours of tempering. At 400° C, all the steels, showed secondary hardening. Initially there was a drop in hardness, but there was significant hardening thereafter. In steel C the secondary hardening occurred in a very short period and the peak was observed after 1½ hours of tempering. In steels A and B the peaks were observed after aging at 400° C for. about 40 hours.

Tempering at 500° C showed secondary hardening peaks in steels A and B, but none in steel C. In all cases, once the peak hardness value was attained, further tempering showed a drop in hardness. At 600° C, all the steels displayed a comparatively fast rate of softening.

(II) *Tempering of Normalized Steels.*—Figures 1, 2 and 3 also show the hardness change with tempering time at 400 and 500° C for normalized steels. The as-normalized hardness of steel C was again very high as compared with steels A and B due to its higher carbon content[14].

At 300° C, the tempering of steels showed initially a small increase in hardness. Only after prolonged tempering, i.e., after about