Effect of carbon on mechanical properties in Fe₀.₅Co₀.₅ alloys

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Effects of carbon addition on brittleness and ductility in equiatomic iron—cobalt alloys have been investigated. In alloys containing 0.5 to 2 at % C, which are ductile when quenched from 800°C, it is found that brittleness occurs due to decarburization, but ductility is reobtained by the recarburizing of the specimens when preceded by decarburization. This is shown to be independent of factors, such as coarsening of the grains occurring during heat treatments, existence of impurities and the formation of texture produced during cold rolling, and the existence of carbon is an important factor. In addition, it is described that the alloys, having generally been very brittle in the ordered state, have not always shown embrittlement even after ordering, if only cold rolled severely. The effectiveness of carbon in improving the ductility has been discussed under a proposal that host atoms, iron or cobalt, react with carbon atoms to precipitate carbides; around the individual carbides, zones, with the deviation from the equiatomic composition, are formed, thus rendering the ordering difficult; in other words, since production of the resultant unequiatomic zones corresponds to that of disordered ones, it would be expected that the ductility of such specimens depends on the morphology of distribution of the zones, such as volume fraction, uniformity and density.

1. Introduction
Equiatomic FeCo alloys are too brittle to be cold rolled, but small amounts of additive elements such as vanadium or chromium can improve the ductility considerably, as is well known. In a previous paper, besides these elements, the following elements have been shown to affect ductility: carbon, molybdenum, tungsten, tantalum, niobium and nickel [1].

The fact that carbon is effective gives a favourable condition for the investigation of the effects of additive elements. Easy diffusion of carbon in metals can make decarburization or carburization possible. With these treatments, only the effect of an impurity may be separated from any factors, since the changes occurring in the FeCo alloys can be indicated as a function of carbon alone.

We show that the action of impurities is not the main factor for the brittleness of FeCo alloys and that the existence of carbon has an important role: the carbon forms carbides, the formation of which results in, around the individual carbides, the zones that are denuded of cobalt atoms and this makes the ordering of a CsCl type structure difficult. The formation of the carbides corresponds eventually to that of disordered zones and thus the improvement of the ductility would depend on the distribution morphology of the zones.

2. Experimental procedures
The materials used were composed of high-purity electrolytic iron and cobalt, and 99.99 wt % pure carbon. Ingots were prepared in vacuo by high-frequency induction melting. Weights and sizes of the ingots cast were 6.5 kg with a square section of 70 mm and 890 g with a 35 mm diameter for 2 and 0.5% carbon, respectively. The large ingot, after heating at 1200°C for one hour, was forged to a square bar of side 30 mm, and then hot-rolled into two kinds of plates: 5 and 1 mm in thickness with 50 mm width. The 5 mm plates were reheated at 800°C, iced-brine quenched, and then cold-rolled to 90% reduction. The small ingot was
heated at 1050°C for ten minutes, forged to a square bar of side 15 mm, and hot-rolled to two kinds of plates of 5 and 1 mm thickness with 20 mm width. The 5 mm plates were cold-rolled to 90% after reheating at 800°C for ten minutes and quenching in iced-brine water.

Decarburization was carried out in a wet hydrogen stream (20°C Dewpoint) at 900°C or 1050°C for ten hours, using specimens of 0.5 mm thickness prepared by cold rolling. On microscopic observation, progress of the decarburization was checked and could be recognized as having been achieved perfectly for the majority of the test pieces used, although a difference in grain size was found in both treatments, namely 900 and 1050°C.

Carburization was carried out in a stream generated from butane gas, at 930°C for three hours (carbon potential of the gas was 1.2%). Carbon contents resulting from the heat treatment were checked by microscope only, no chemical analysis being performed. According to the observation, carbon could be estimated to be over 0.5% in specimens under both conditions.

A method of replicating was employed for the determination of carbide compositions: they were mechanically extracted from deeply etched specimens by cellulose film, fixed with carbon film vaporized on the carbides, scooped onto copper mesh after dissolving the cellulose and washing the carbon film obtained, and then they were submitted to measurement. These carbides were measured by a H-700H analytical electron microscope attached with a Kevex’s energy dispersive spectrometer, operating at 200 kV. For the observation of structural changes, a H-500 transmission electron microscope was used operating at 125 kV.

An X-ray diffractometer was used for determining the long-range order parameter, S, with CoKα radiation. Line intensities and profiles were measured and the parameter S was evaluated from the ratio of the superlattice (100) to the fundamental (200) line intensity.

Tensile testing was carried out with a crosshead rate of one millimetre per minute. The specimen dimensions were 20 mm in gauge length, 2 to 3 mm in width and 0.5 to 1 mm in thickness.

For metallographical testing, a solution of 5% nital was used for etching and extraction replicating; a 95% CH₃COOH—HClO₄ solution was used for foil observations.

Heat treatments were performed in salt baths for ordering, and in a tube furnace, with streaming argon gas, for heating at temperatures over 800°C.

3. Experimental results
3.1. Structures and mechanical properties in annealed states
An as-cast structure of the alloy containing 2% carbon is shown in Fig. 1. Pearlite, the black regions, lies in a ferritic matrix (white). A martensitic structure was not obtained even with quenching from 1100°C where only an austenitic phase exists. The quenching led to a finer structure of pearlite. The plate-like carbides in the pearlitic structure were observed to easily form spherical carbides when heated at temperatures between 750 and 900°C; for example, in the specimens which were severely cold-rolled, such carbides occurred within five minutes of heating at 800°C. This spheroidization strongly affected workability and allowed cold rolling up to 90% to be accomplished, although with the pearlitic structure no cold rolling was undertaken, because of hardening, except up to about 25% reduction. In Fig. 2a spheroidal structure, obtained by heating 2% carbon alloy at 800°C for one hour after hot rolling, is shown, with no pearlitic structure.

Table I shows effects of annealing on mechanical properties. When as-hot rolled, the 2% carbon alloy is very brittle, no ductility being observed. Quenching from 800°C, however, causes a recovery in ductility, irrespective of the differences in carbon content and in rolling conditions. Brittleness of as-hot rolled specimens seems to be due to the formation of a superlattice which occurred during slow cooling from the high temperatures. Therefore, heating to over 800°C and quenching from