CHRI-A 73-0055

Reprinted from
Philosophical Magazine, Vol. 27, No. 2, p. 281, February 1973

Shock Deformation of K-state in Ni–Cr Alloys

By Aristos Christou†
Materials Science Division, Naval Weapons Laboratory,
Dahlgren, Virginia 22448, U.S.A.

and Norman Brown
School of Metallurgy and Materials Science,
and The Laboratory for Research on the Structure of Matter,
University of Pennsylvania, Philadelphia, Pennsylvania 19104, U.S.A.

[Received 25 April 1972 and in final form 5 September 1972]

Abstract

The change of electrical resistivity was used to study the ordering kinetics and the anomalous resistivity behaviour in Ni–22 wt. % Cr and Ni–30 wt. % Cr (Ni–22 Cr and Ni–30 Cr) before and after shock deformation. Ordering was found to occur in two stages : the attainment of an equilibrium domain size, and the increase of long-range order (LRO) within the domains. Specimens of Ni–22 Cr and Ni–30 Cr in the ordered and disorderd states were subjected to explosive shock loading at shock pressures between 90 and 300 kbars. In the pressure range of 200 to 300 kbars, the resistivity of the ordered alloys decreased sharply. The resistivity of the shock-deformed initially quenched alloys decreased continuously between 90 and 300 kbars. The decrease in resistivity with shock deformation for the quenched alloys was related to the destruction of short-range order (SRO).

§ 1. Introduction

Commercial nickel alloys containing chromium have been used as electrical resistance and thermocouple materials for a number of years. There has been much work in recent years in understanding the type of ordering that exists in the Ni–Cr system between 23 and 30 % Cr. X-ray structural studies in this system are difficult due to the similarity in scattering power of the nickel and chromium atoms. A number of investigators (Taylor and Hinton 1952, Manene 1959) have attempted to obtain useful evidence by studying nickel–chromium alloys slightly alloyed with an element such as aluminium that facilitates x-ray studies. The interpretation of these results is open to question because of an additional high-temperature transformation that occurs in the ternary alloy, consistent with the precipitation and the re-solution of a second phase. The x-ray investigation by Baer (1959) has clearly established that a 30% Cr alloy should form LRO if annealed sufficiently long.

The structural condition known as K-state has been extensively studied in Ni–Cr alloys containing 10 to 40 at. % where it occurs to a

† Present address: Naval Research Laboratory, Washington D.C. 20320, U.S.A.

SEP 17 1973

pronounced degree. The K-state phenomenon dates from the work of Thomas (1942) on electrical-resistance alloys. An increased value of the electrical resistivity is the most characteristic change in properties that accompanies the formation of K-state in a suitably treated alloy. Roberts and Swalin (1957) reported the absence of long-range order in a neutron-diffraction study of a Ni–Cr alloy heat treated to produce K-state. Bagaryatski and Tyapkin (1958) studied the diffuse x-ray scattering from single crystals of Ni–Cr alloys and concluded that domains about 50 Å in size approximating the composition of the ordered phase Ni_2Cr are characteristic of K-state. Ordering in Ni–Cr was studied by neutron diffraction employing polycrystalline specimens and single crystals (Gomankov, Litvin and Loshmanov 1962). Reflections characteristic of the Ni_2Cr superstructure, linked with the original lattice indicated by Bagaryatski and Tyapkin (1958) were found in the single crystal. No superstructure reflections were detected in the polycrystalline specimens, and this was attributed to the low sensitivity of the powder method employed. From a study of conductivity and Hall constant, Köster and Rocholl (1957) concluded that K-state in Ni–Cr alloys involves short-range order and a change in the average distribution of electrons and holes in the upper energy levels.

Additional investigations of the physical properties of Ni–Cr alloys have concentrated on the anomalous variation in the temperature dependence of electrical resistivity (Taylor and Hinton 1952, Nordheim and Grant 1953, Selissikiy 1962, Yano 1940). Specific heat determination has indicated an anomalous variation which is also sensitive to the initial heat treatment (Stransbury, Brooks and Arlege 1966).

1.1. *Deformation of Ni–Cr Alloys*

Recent tensile deformation and neutron irradiation experiments on Ni–Cr alloys have indicated that order-induced hardening is present in Ni–Cr alloys. Selissikiy (1962) studied the strengthening of Ni–Cr alloys after low-temperature annealing. Alloy compositions from 18 to 33% chromium were cold worked 97% and then annealed at low temperatures. Strengthening was observed below the recrystallization temperature of 575°C. At concentrations between 23 and 33% chromium an additional strengthening peak due to short-range order was observed. Neutron irradiation of a Ni–21 wt. % Cr alloy increased the ultimate tensile strength, and promoted further transformation to the K-state in a cold-worked and quenched alloy (Astrahantzev and Konnov 1966). An investigation of recovery kinetics in a cold-deformed Ni–Cr alloy revealed three recovery stages. The second recovery stage is associated with migration of vacancies while the third is connected with the migration of interstitials (Karpov and Panova 1963).

In summary, to date, no mechanical property data are available on the effect of high strain rates and the formation of K-state in Ni–Cr alloys.