HELIUM EFFECT ON PHASE STRUCTURAL CHANGES IN CARBON STEEL UNDER POST-IRRADIATION PHASE RECRYSTALLIZATION

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In the present paper a new radiation effect related to thermally irreversible structural changes during post-irradiation phase transformation in a-particle irradiated region of the sample of the U7 steel [0.7°/; carbon) is demonstrated.

The samples of the U7 carbon steel have been irradiated at the cyclotron with α-particles with energies of 29 and 50 MeV up to dose $1.5x10^{17} cm^{-2}$ and with protons with energy of 10 MeV up to dose $2.5x10^{17}$ cm^{-2} at temperatures not more than 100^0 C

The results of metallography study of as-irradiated, annealed and carburized after full decarburisation samples allow to establish two important facts. First, the irradiation of the U7 carbon steel with high-energy protons and alpha-particles which results in formation of radiation defects and hydrogen doping leaves any structural changes invariant in the process of post-irradiation annealing at temperatures 400-1100^{0}C. Second, due to post-irradiation annealing in the range of temperatures above the α-γ-transition temperature in the helium doped sample regions of the U7 steel observes thermal irreversible structural changes (perhaps phase changes too): the formation of fine-grained ferrite-pearlite structure with an essential superiority of ferrite phase portion.

It might be assumed that the main reason of the observed effect: is thermally stable complexes of helium atoms and vacancies in the form of helium bubbles rather than radiation defects.

Introduction

In the work [1] one has found a new phenomenon in carbon steels irradiated with high-energy alpha-particles. It involves the formation of fine-grained ferrite-pearlite structure with simultaneous essential increase of ferrite phase fraction in local volumes of steel sample exposed to alpha-particles bombardment and post-irradiation annealing at temperatures of austenitic region of Fe-C diagram.

In this connection it is of interest to define the role of radiation defects and helium atoms in phase changes of carbon steel under post-irradiation α-γ- transformation.

Experimental

As an object of investigations the U7 carbon steel *(0,7%* carbon) has been taken. After annealing in vacuum at 850^{0}C for two hours ferrite-pearlite structure with a ferrite component distributed along the pearlite grain boundaries has been produced in samples. The samples have been irradiated at the cyclotron with alpha-particles with energies of 29 and 50 MeV up to dose $1.5x10^{17}$ cm^{-2} and with protons with energy of 10 MeV up to dose $2.5x10^{17}$ cm^{-2} at temperatures not more than 100^0 C.

Two methods of irradiation with α-particles and protons have been applied. They are differ from one another by the condition of formation of zone doped with helium or hydrogen, respectively, in volume of samples (see Fig.1). As seen from Fig.1a under irradiation by the first method (method 1) the zone doped with helium (or hydrogen) is parallel to the bombarded surfaces at a depth corresponding to projective range of charged particles. The helium (or hydrogen) doped zone formed by irradiation on the second method (method 2, see Fig.1b) has a shape of a "chute" separating the local irradiated zone from unirradiated matrix. Similar shapes of doping zones located on the bombarded sample surface at regular intervals have been produced under special irradiation conditions.

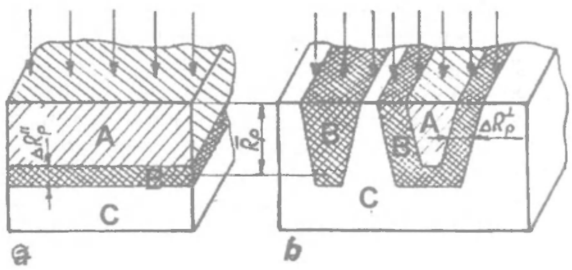

Fig.1. The scheme zones production in samples of the U7 steel irradiated with high-energy particles by the method 1 (a) and method 2 (b): A - the region of alpha-particles (proton) "shooting through", B - the helium (hydrogen) doped region, C - unirradiated region, R_p - projective range of charged particles, $\Delta R^{\parallel}$ - longitudinal straggling, $\Delta R^{\perp}$ - lateral straggling.

After irradiation the samples have been annealed in vacuum at temperature between 400 and 1200^{0}C. Some irradiated samples after total decarburization at 1200^{0}C have been exposed to one-side carburization (on the bombarded surface side) in activated carbon powder at 950^{0}C. Carburizing treatment has been performed by two consequent stages to form a carburized case depth of 0,3 mm and up to total carburlzation of the whole sample volume.

The phase and structural changes in irradiated and unirradiated regions of samples have been detected by means of optical microscopy and microhardness measuring.

Results

After irradiation both with alpha-particles and protons no structural changes have been observed in the investigated samples.

Microhardness measuring both on the bombarded surface and along the direct of particle motion showed the presence of radiation strengthening.

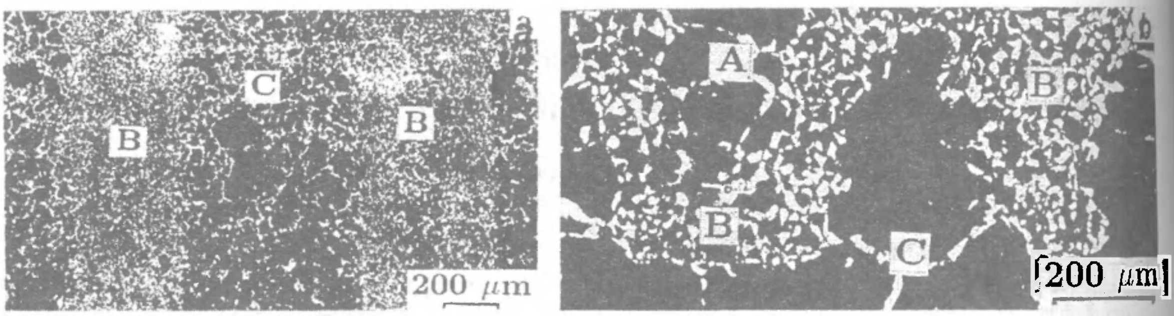

Fig.2. Structural changes in the regions of the U7 steel sample irradiated with alpha-particles by the method 2 and annealed at 900 C. a - structure of bombarded surface, b - structure along the direction of alpha-particle motion., A - r of irradiation-for"shootingthrough", B - helium doped region, C unirradiated region.

Metallographic investigations of all as-irradiated and annealed at temperatures 400-600^{0}C samples have not revealed any changes in pearlite structure. Temperature increase of post-irradiation annealing up to 900^{0}C has left structural state of the U7 steel irradiated with protons. Only in samples irradiated with alpha-particles after annealing at 900^{0}C the essential structural changes have been observed (Fig.2). As seen from figure in the irradiated sample regions firstly, fine-grained ferrite-pearlite structure is produced, and secondly, the portion of ferrite phase practically is doubled. Taking into account the absence of an analogous structural change in the U7 steel irradiated with protons [both in the region of "shooting through" with protons or alpha-particles and in the region of hydrogen doping) one can conclude that the presence of helium atoms in steel is a necessary condition for revealing the phenomen of structural changes in the carbon steel after irradiation and post-irradiation phase recrystallization.

The increase of the time of post-irradiation annealing at 900^{0}C up to 6 h and further increasing of annealing temperature up to 1100^0 C showed that the above-mentioned phenomen of anomalous structural change in the helium doped region of the U7 steel sample is conserved. The temperature increase of post-irradiation annealing of the given sample up to 1200^{0}C (for 1 h) has resulted in its total decarburization and large helium bubbles formation in the helium doped regions.

In this connection, it was interesting to establish the fact of thermal irreversibility of the observable anomalous structural change in the helium doped U7 steel under post-irradiation phase recrystallization by means of carburization of the irradiated sample which decarbornizing treated by post-irradiation annealing at 1200^{0}C. For this purpose the given sample has been subjected to one-side (on the bombarded side) carburization in activated carbon powder at 950^{0}C for 5 and 15 minutes. Typical microstructures of the samples after one-side carburization at a depth of 0,3 mm (5 min) and till total carburization of the whole volume (15 min) are shown in Fig.3. It is well seen that the effect of anomalous structural change in helium doped sample zones manifesting in fine-grained ferrite-pearlite structure formation with an essential superiority of ferrite phase portion has been repeated. This proves conclusively the thermal irreversibility of the helium effect on phase and structural changes in the carbon steel under post-irradiation phase recrystallization.

Therefore the above results allow one to emphasize two important facts. First, the irradiation of the U7 carbon steel with high-energy protons and alpha-particles which results in formation of radiation defects and hydrogen doping leaves any structural changes invariant in the process of post-irradiation annealing at temperatures 400-1100^{0}C. Second, due to post-irradiation annealing in the range of temperatures above the α-γ-transition temperature in the helium doped sample regions of the U7 steel observes thermal irreversible structural changes (perhaps phase changes too): the formation of fine-grained ferrite-pearlite structure with an essential superiority of ferrite phase portion.

From the above it might be assumed that the main reason of the observed effect is thermally stable complexes of helium atoms and vacancies in the form of helium bubbles rather than radiation defects.

References

1. *Reutov V.F., Turubarova L.G, Silnyagina N.S.* Influence of post-irradiation phase recrystallization upon structural changes in carbon steels irradiated by high-energy alpha-particles.// Scripta Metallurgica, 1993, v.29, p.807-810.

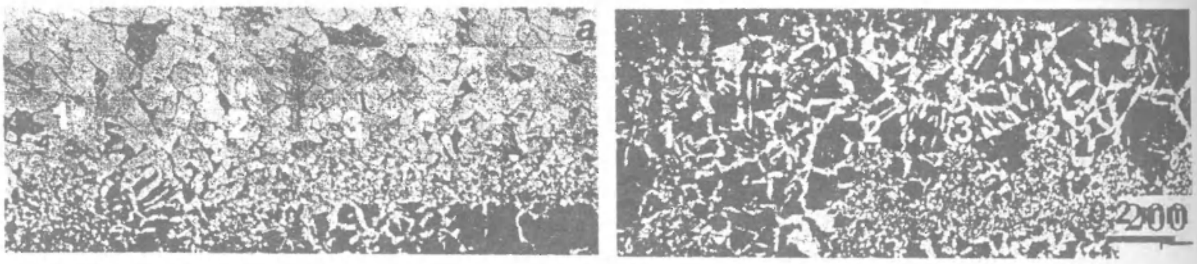

Fig.3. Structural changes in U7 steel after α -particles irradiation, decarburization at 1200^0 C and followed by one-side carburization (on bombarded surface side) at 950^0 C for 5(a) and 15 (b) min