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# SATURATION OF STEEL WITH CARBON BY THE ACTION OF IMPACT WAVES

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When metal surfaces are acted upon by impact waves there is a considerable strengthening effect. Under certain conditions dynamic plastic deformation is accompanied by heating; in particular with impact speeds of 4000 m/sec iron recrystallizes [1, 2]. When iron was heated by laser light with a pulse duration of $10^{-3}$ sec it could become saturated with carbon to a depth several orders of magnitude greater than the possible depth of penetration of carbon by solid-state diffusion [3]. Anomalously large zones of carbon saturation were observed at the boundaries of graphite and ferrite grains in cast-iron that was exposed to light pulses.

It was of interest to study the possibility of saturating iron with carbon by the application of impact waves. The iron-carbon pair was selected for preliminary study because carbonization has been thoroughly studied under a variety of conditions [4] but not including those of dynamic loading.

The studies were made on annealed low carbon steel St. 20 with ferritic-pearlitic structure.

The tests were made with the procedure for hardening steel plates described in [6]. A plate of low-carbon steel, mounted on a heavy steel base, was covered with a uniform layer of graphite powder. The graphite was driven into the low-carbon steel by impulse loading. This loading was produced by using explosives to throw a thin plate of the same steel onto the test-piece at a speed of 1975 m/sec. Sheet plastic explosive was used with a detonation velocity of 7500 m/sec and density of 1.65 g/cm$^3$; it was detonated with a capsule detonator. The impact pressure was 425 kbars. In order to carbonize a thin plate from both sides the experimental procedure was somewhat altered. A sheet of low-carbon steel with a layer of graphite powder was placed between the bedplate and the explosive. thrown sheet. This impact scheme gave a travelling impact wave. After the treatment specimens were cut from the plate in a direction perpendicular to the front of the impact wave, and were studied by metallographic and x-ray structural analysis; the microhardnesses of the structural components were also measured.

X-ray studies of the phase composition of the specimen surfaces showed that in the initial state, (within the sensitivity of the analysis) the material consists only of ferrite with a volume centered cubic structure ($\alpha$ phase). After treatment with explosives and smoothing the surface by grinding, x-ray investigation revealed only very weak lines of the $\alpha$ phase, and the principal phase component was cementite. The relative intensity of the cementite line was compared with that observed on reference specimens of iron-carbon alloys of various compositions. The relative intensity corresponded approximately to that obtained on transeutectic white cast irons (about 4.5% C). The sudden change in the phase composition of the steel during carbonization by an impact wave can be seen by comparing the intensity curves on the x-ray graphs shown in Fig. 1.

Prolonged etching (0.5 h) in 4% alcoholic solution of nitric acid revealed the structure of the carbonized white layer (Fig. 2) which was acicular, similar to that near a cooled melt, which was observed when white cast iron was irradiated with laser light impulses. The structure of the white layer indicates a high carbon content.

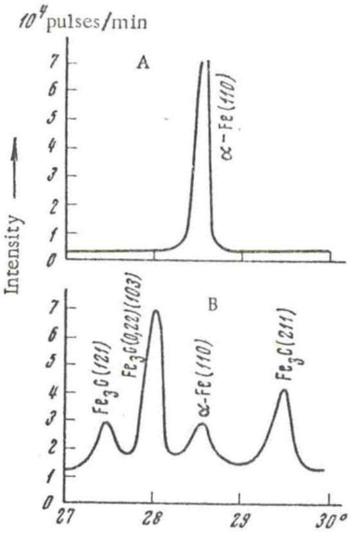

Fig. 1. Curves of intensity of lines on x-ray graphs for low carbon steel 20 (0.2% C). A) before and B) after saturation with carbon in an impact wave.

Study of the structure in the section perpendicular to the carbonized layer (in the direction of propagation of the impact wave) showed the following sequence of structures. The carbonized layer is thin (about 0.05 mm) and very hard (from 580 to 935 kgf/mm$^2$), and its boundary is very sharp. The zone of carbon saturation contains round pores apparently caused by the evolution of a gas phase.

The next is the zone of thermal influence; it is up to 0.05 mm thick, and in addition to ferrite grains of hardness 160-190 kgf/mm$^2$ it also contains grains which in the initial state had pearlite structure (Fig. 3). During impulse heating these grains were converted to austenite containing 0.8% C, and on sudden cooling a martensite-austenitic structure was formed in them with hardness 460-760 kgf/mm$^2$. In the ferrite regions surrounding these grains, as a result of transition of the $\alpha$ phase to the $\gamma$ phase during heating, and inverse transition during cooling, the grain structure became finer. Therefore, the heating and cooling rates were so high that the carbon could not be redistributed between the pearlite being converted into austenite and the ferrite. The structure is also typical of the zone of thermal influence when steel is treated by laser light impulses [5].

The next polygonization zone is two orders of magnitude (5-6 mm) and contains fine polygonal blocks which retain residues of twins. This very hard structure (250−260 kgf/mm$^2$) was apparently formed by short-time heating of the metal after dynamic plastic deformation.

Finally, the last zone, which forms the main structure of the specimen deformed by impact waves, contains a considerable number of twins in grains of ferrite of hardness 160-180 kgf/mm$^2$, which is somewhat harder than the ferrite in the initial material (150-170 kgf/mm$^2$).

On the basis of the structural studies the following physical mechanism can be proposed for processes that lead to iron being saturated with carbon in exposure to impact waves. A shock wave that occurs on collision with the plate compresses the porous layer of graphite powder. Here in addition to being subjected to high pressure the powder is heated to a temperature higher than the

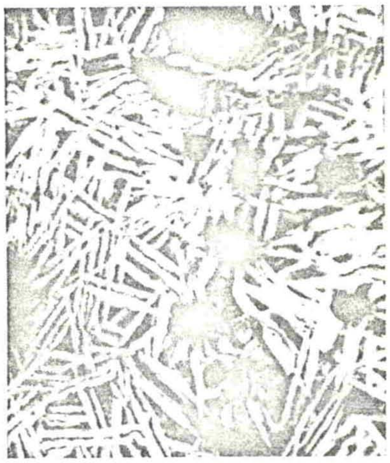

Fig. 2. Microstructure of carbon saturation zone after deep etching. × 1000.

Fig. 3. Microstructure of carbon saturation zone and thermal influence after weak etching. × 450.

melting point of iron. This produces a layer of carbon in solution in liquid iron. Then the melt hardens and excess carbon is evolved in the form of needles of cementite. The reduction in the melting temperature of iron in contact with graphite also plays a part, because the iron-carbon diagram is of the eutectic type. The small thickness of the thermal influence zone indicates that there are very severe temperature gradients during cooling of the melt. The significant polygonal zone that was observed with dimensions two orders of magnitude greater than those of the saturation and thermal influence zones is also of interest. The existence of this zone is apparently associated with the total effect of heating in the impact wave heating by heat transfer from the metal surface. From the appearance of the structure it seems that the initial process is twinning, which is only later followed by polygonization.

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