REPAIRING DEFECTS OF THE OPEN CRACK TYPE BY A DIFFUSION METALLIZATION METHOD

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It was demonstrated that it is possible to "heal" defects of the open crack type of various origins in structural steels by the formation of diffused copper and chromium coatings. This method makes it possible fully or partially to restore to steel its compactness and strength, especially its fatigue strength in air and in corrosive media.

Many machine and instrument parts become unserviceable because of the formation of cracks on their surface. There are various methods of repairing ("healing") these cracks, i.e., of restoring the initial quality of the metal surface and the required level of mechanical properties. We investigated the possibility of "healing" defects of the deep open crack type of various origins by thermal diffusion of copper and chromium into damaged part surfaces.

Fig. 1. Corrosion-fatigue cracks in steel 45 before "healing" (x40).

Fig. 2. Corrosion-fatigue cracks in steel 12KhN3A after "healing" by the diffusion of copper (x40).

The experiments were carried out on low- and medium-carbon steels and on alloy steels. The cracks on experimental specimens were produced by fatiguing them in air (in the elasto-plastic range) or in a corrosive medium (in the elastic range). In the former case the crack walls did not oxidize, in the latter the cracks were filled by the corrosion products (Fig. 1). In both cases the depth of cracking was controlled by varying the number of fatigue cycles without, however, allowing the fracture to take place.

Diffused copper coatings on steel 20, 45 and 12KhN3A specimens were produced by a gaseous contact method in a mixture containing copper powder, finely ground fireclay powder and ammonium chloride [1]. Chromizing was done in a mixture of ferrochromium, alumina and ammonium chloride [2]. Both treatments were applied at 1100-1200°C for 4-5 hr.

Test results (Fig. 2) showed that the diffusion of copper leads to the formation of a diffused layer on the specimen surface and on the crack walls; the thickness and structure of this layer depend on the treatment conditions. The layer consists of a solid solution of copper in α-iron and pure copper which, owing to its limited solubility in α-iron, is precipitated in the form of a continuous surface layer and in the form of separate grains (formed when a specimen is cooled slowly after diffusion treatment) distributed in the diffused layer [1]. Copper at 1100-1200°C is liquid and surface active with respect to steel; as a result of capillary flow and adsorption migration it spreads readily on the crack walls toward the crack tip, diffusing at the same time into the metal. If the crack width is commensurate with the diffused layer thickness formed on the outer steel surface, cracks of this kind may be fully "healed" by a solid solution of copper in α-iron. In isolated cases grains of pure copper are formed preferentially in the crack mouth region where the total
copper concentration is relatively high. The strength of a solid solution of copper in \( \alpha \)-iron is quite high. And so, after diffusing copper into steel 45 the microhardness of copper, ferrite and the solid solution of copper in \( \alpha \)-iron is, respectively, 105, 180 and 320–470 kg/mm\(^2\). The microhardness of a solid solution of copper in alloyed iron in steel 12KhNRA reaches 650–670 kg/mm\(^2\).

It should be pointed out that the diffusion of copper is an effective means of "healing" both cracks with no evident signs of oxidation and cracks filled with corrosion products. The cleanliness of crack walls is not an important factor because, as was proved by special experiments, any corrosion products are reduced at elevated temperatures by hydrogen produced as a result of decomposition of ammonium chloride. No exfoliation of the diffused layers was observed when specimens with defects healed by copper diffusion were subjected to various mechanical tests.

Defects of the open crack type are also "healed" by chromizing of steel. Since the melting point of chromium and chromium-iron alloys are very much higher than the chromizing treatment temperature, the adsorption migration of liquid chromium into cracks cannot take place. In this case, chromium chlorides formed as a result of a reaction between hydrogen chloride and ferrochromium easily find their way into the defects where chromium atoms become adsorbed on crack walls and diffuse into the metal.

Diffusion chromizing of steel 45 by the above described method "heals" any cracks present (Fig. 3). The structure of the diffused layer formed in a crack is complex and depends both on the composition of steel and on the chromizing conditions. In the case of a medium-carbon steel this layer comprises a solid solution of chromium in \( \alpha \)-iron, in the central portion of which there is a band of complex carbides. The solid solution is separated from steel by a layer enriched in outward diffusing carbon (a pearlitic zone).

It was of a considerable practical interest to study the effect of the above described methods of repairing surface damage of parts on their strength, especially on their fatigue strength which is particularly sensitive to the surface condition, to the presence of structural and geometrical stress raisers, and to other factors. This series of experiments was carried out on steel 45 specimens with corrosion-fatigue cracks produced by preliminary cyclic deformation in a 9% NaCl solution at a stress amplitude of \( \pm 15 \) kg/mm\(^2\) for \( 10^6 \) and \( 2 \times 10^6 \) cycles. One part of the specimens was subjected to a 8 hr copper diffusion treatment at 1150° C followed by a 2 hr diffusion annealing at 840° C (to refine the grain structure of steel). The other part of cracked specimens was given a 2 hr vacuum annealing treatment at 840° C. The specimens (with the gauge portion 8 mm diam.) were then fatigue tested in rotating bending at a frequency of 50 cps.