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Composite Mechanism of Scale Adhesiveness

Kompozitni mehanizem oprijemljivosti škaje

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In the scale which is formed on the surface of alloys during the annealing process, metallic and oxidic phases are interwoven in various ways, which are characterized by the shape, portions, and size of both phases. Ductile scale component enables certain deformation of the scale, and it hinders propagation of cracks in the brittle oxidic phase.
Key words: scale, composite material, crack, propagation, separation, adhesiveness.

V škaji, ki nastane med žarjenjem na površini zlitin, se kovinska in oksidna faza prepletata na različne načine, ki jih karakterizira oblika, delež in velikost obeh faz. Duktilna sestavina škaje omogoča določeno deformacijo škaje in preprečuje širjenje razpok, nastalih v krhki oksidni fazi.
Ključne besede: škaja, kompozit, razpoka, napredovanje, ločitev, oprijemljivost.

Scale is product of the high temperature oxidation of metals and alloys. Structure of scale depends on the chemical composition of alloy, temperature atmosphere and on the time of annealing. The scale which adheres to metal during working and service reduces in most cases the quality of the surface of product. Therefore it should be removed in single stages of technological process. The most simple ways of scale removal are mechanical forces which appear due to temperature changes or in working.

Scale and metal differ in their physical properties, among others, also in all mechanical properties and in thermal expansion. Great differencess in thermal expansion during the temperature changes cause stresses which practically separate both constituents, or they fractured only oxide. Scale adhesiveness depends on the microstructure, geometry of constituents, and the boundary with the metallic matrix.

Due to properties and the way how scale constituents are interwoven, and depending on its properties, the scale can be treated as a composite material.

Composite materials have different properties in comparison to the properties of constituents. One of essential characteristics

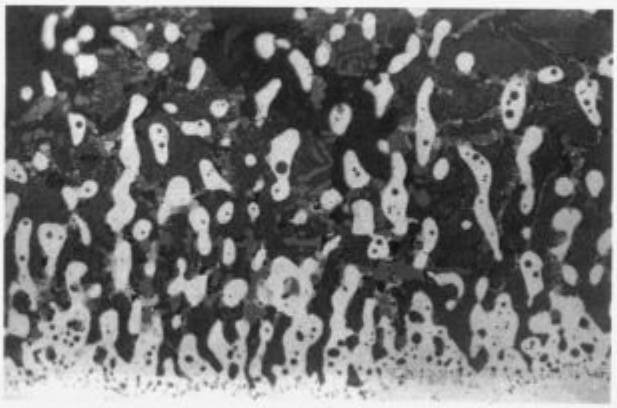


Fig. 2: Scale region with pronounced composite structure, with long, wide and overlapping metallic lamellae which successfully stop the propagation of cracks (200 x)

Slika 2: Del škaje z izrazito kompozitno zgradbo, dolgimi, širokimi in prekrivanimi lamelami kovine, ki dobro zaustavljajo razpoke (200 x)

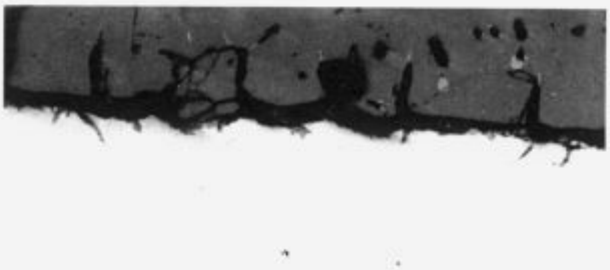


Fig. 1: Well defined simple boundary between scale and parent metal in carbon steel (200 x)

Slika 1: Dobro definirana enostavna meja med škajo in kovino v ogljikovem jeklu (200 x)

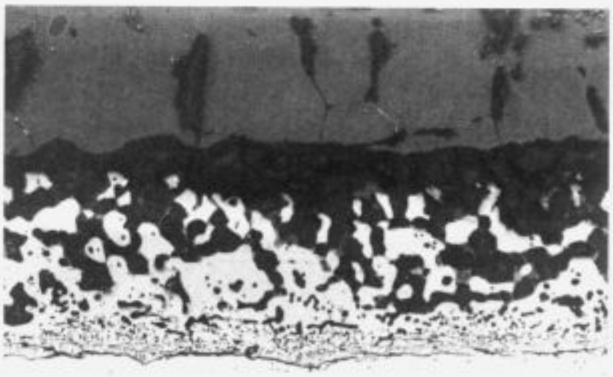


Fig. 3: Weak regions in the scale on the boundary between composite and oxide part

Slika 3: Šibka mesta v škaji na meji, ki loči oksidni del od kompozitnega

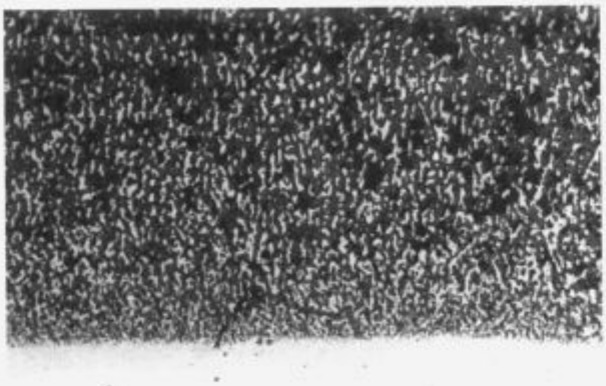
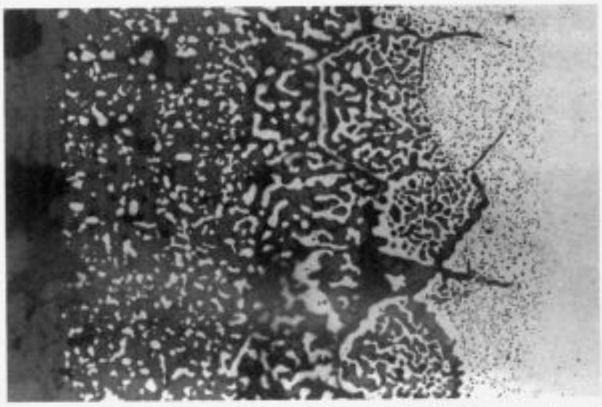


Fig. 4: Composite scale with a great amount of metal phase, which is not able to stop the crack propagation (100x)

Slika 4: Kompozitna škaja z veliko kovinske komponente, ki nisposobna ustavljati razpoke (100x)

of composite materials is crack arrest. In composite materials with ductile matrix (e.g. metallic or of polymers) cracks appear usually in rigid constituents of the armature (most frequently in fibres), while in composite materials with ceramic matrix and ductile fibres the situation is reversed.

In the scale the nonmetallic constituents are always more brittle than the metallic ones, and they have also more defects which appear already during the growth. Portion, way of being interwoven, and geometry of both constituents determine the ability for stopping crack propagation and thus the obstinacy with which the scale resists to separation from the metal. In the cases, illustrated in **Figs 2, 5** and **6**, the microstructure has such portions of metallic constituent, and such combination of both phases, that separation on the boundary with pure metal cannot be expected, and scale can be removed only by additional machining of the surface. On pure metals the scale has usually a well defined boundary with the metal. The oxide metal boundary is the weak point for ideal fracture and thus good separation of scale from metal (**Fig. 1**). In alloys the metallic and oxidic con-



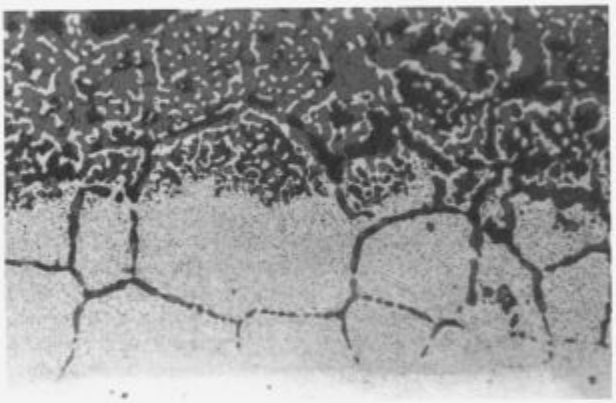


Fig.5,6: Weak directions for crack propagation in the compositescale with variously big metal "fibers", and along boundaries rich with oxide of alloying element (Cr) (200x)

Sl. 5,6: Šibki mesti na meji dveh kompozitnih con z različnovelikimi "vlakni" kovine in vzdolž mej, bogatih z oksidom legirnega elementa (Cr) (200x)

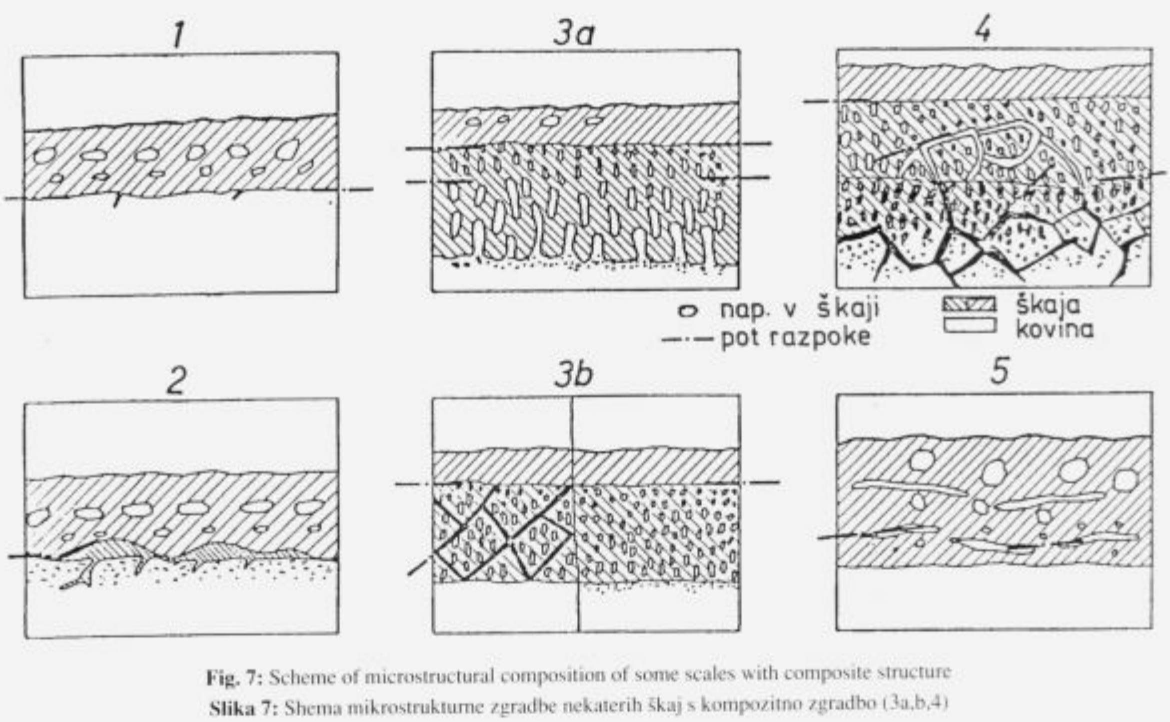


Fig. 7: Scheme of microstructural composition of some scales with composite structure

Slika 7: Shema mikrostrukturne zgradbe nekaterih škaj s kompozitno zgradbo (3a,b,4)

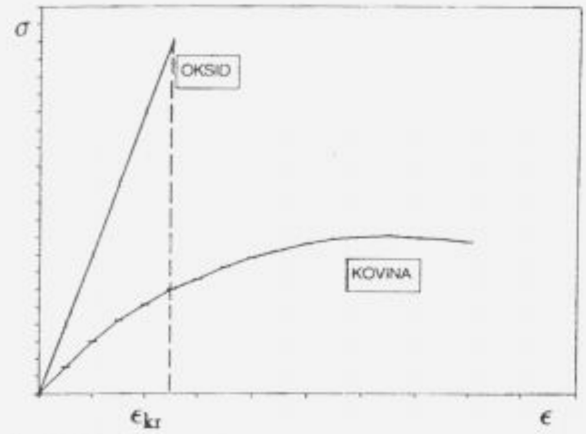


Fig. 8: Variations in mechanical characteristics of oxyde and metal in the scale

Slika 8: Razlike v mehanskih lastnostih oksida in kovine

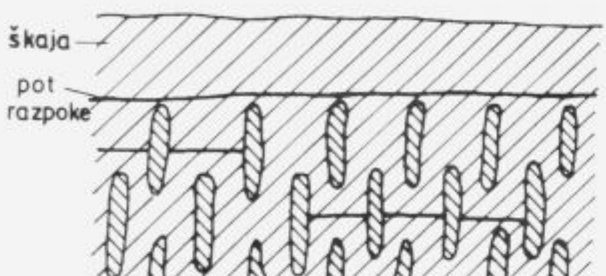


Fig. 9: Arrest of crack propagation in oxide on the metallic fibres

Slika 9: Ustavljanje širjenja razpok v oksidu na vlaknih kovine

stituents are most frequently interwoven, the boundary between scale and metal is not even which highly renders the separation of both phases more difficult (**Fig. 2**).

In steels composed of elements with thermodynamic properties different from those of iron, the scale of heterogeneous composition is formed. In the lower part of scale, metal and oxide particles are interwoven. This part behaves under mechanical loading identically to composite materials. The stresses which appear due to temperature variations or other loads can cause cracks in the oxide. Their propagation can be stopped by suitably distributed metal in the scale, and thus the fracture of scale is prevented. The weak point in such scales is the surface between the composite zone and the upper scale layer being without metal (**Fig. 3**).

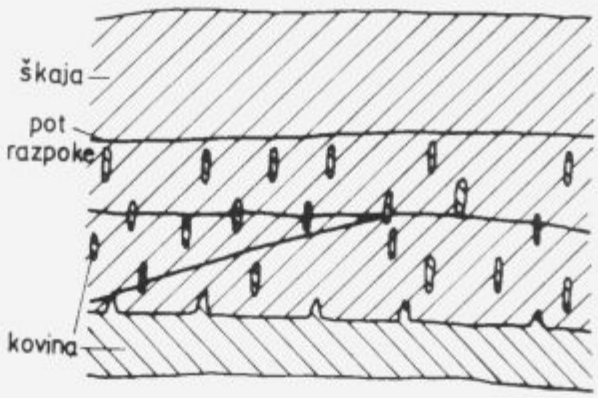


Fig. 10: Crack propagation in composite scale with unfavourable geometry of metallic phase

Sl. 10: Širjenje razpok v kompozitni škaji z neugodno geometrijo kovinske faze.

Some heterogeneous lower scale parts have infavourable shape of metallic phase to stop the crack propagation in oxide. In such a scale crack propagates betweeen metallic grains, and it can even cut some thin grains (**Fig. 4**).

In the oxide grains of parent metal there are also oxides of alloying elements, being either dispersed or predominantly precipitated in certain directions or in form of a net which corresponds to metal grain boundaries before the oxidation. These directions are mechanically weak points in the scale and cracks can propagate along them to parent metall matrix (**Figs. 5, 6**).

Some patterns how the boundary scale metal region is formed, are presented in **Fig. 7**.

Interwoven mineral and metal constituents give to scale all the characteristics of composite materials with the usually predominant oxidic phase also in the respect of microstructure while in the boundary with metal often metallic phase in the scale is prevailing (**Figs. 7, 9** and **10**).

Rigid mineral components render rigidness and compression strength to oxide, but they are very sensitive to various flaws which appear during the growth of such oxide. Metallic matrix of suitable geometry is able to stop cracks, and it increases the adhesiveness of scale (**Fig. 9**).

If a scale which will easily separate from metal is to be obtained, it must be composed mainly of mineral constituents.

Metallic particles being interwoven in the scale, especially if they are also connect with parent metall, can only increase the scale adherence.