TRANSFORMATION OF EUTECTIC NON-METALLIC INCLUSIONS IN STEELS UNDER LASER ACTION

ТРАСНФОРМАЦИЯ ЭВТЕКТИЧЕСКИХ НЕМЕТАЛЛИЧЕСКИХ ВКЛЮЧЕНИЙ В СТАЛЯХ ПРИ ЛАЗЕРНОМ ВОЗДЕЙСТВИИ

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Abstract. Melting and crystallization of eutectic non-metallic inclusions was investigated. It was shown that under laser action the initial structure of eutectic inclusion-steel matrix boundaries transits into unstable equilibrium high-energy condition that cause development of the dissipation processes connecting with aspiration of system inclusion-matrix to the state with minimum of free energy. In the result of the system eutectic inclusion-matrix transits to the state of unstable equilibrium which determines structure and properties of laser-quenched interphase boundary. Processes of melting, fusion and dissolution of eutectic non-metallic inclusions and also of the melting of steel matrix play the great role in transformation of inclusion-matrix boundaries under laser action.
KEYWORDS: EUTECTIC NON-METALLIC INCLUSIONS, STEEL, STRENGTHENING, LASER TREATMENT

1.Introduction. **Most of inclusions of "eutectics"** are low-melting and both their phases must to melt almost simultaneously. But eutectics with high-melting phases exist too, see [1]. Inclusions of eutectics are differed from heterophase non-metallic inclusions "high-melting phase surrounding with low-melting cover" and "phases are beside" with the presence of more dispersed phases and more branching net of interphase boundaries eu1↔eu2 inside inclusions. Molten inclusions "eutectics" is been in molten steel matrix and micrometallurgical bath is formed. Hydrodynamics flows in the conditions of vortex thermocapillary mixing and temperature gradients are origined and that causes displacement of inclusion phases. In the result of high-speed melting of inclusions "eutectics" heavy oversaturated liquid solution or two liquid solutions on the base of inclusion and steel matrix differing by concentration heterogeneity are formed. In such liquid systems nonbalanced mass transfer is happened that suppresses of cooperative growth of phases and formation of cooperative structures of non-metallic inclusion.

The goal of this investigation was to research the processes of melting, dissolution, crystallization of eutectic non-metallic inclusions in hyper-nonequilibrium conditions and the influence of these inclusions on the peculiarities of structural changes in steel matrix and its strengthening under laser treatment.

2. Materials and Procedures. Specimens made of wheel steel R7, 08Yu, 08T, 08Kp, 08Ch18N10T,ShCh15, NB-57, 12GS, E3 were irradiated by laser in GOS-30M installation with an excitation voltage of 2,5kV and pulse energy of 10, 18, 25 and 30J at heating rate of 10^5 $^oC/s$ and cooling rate of 10^6 $^oC/s$ with action time of (1,0, 2,5, 3,6, 4,2 и 6,0)$\cdot 10^{-3}$s. Eutectic non-metallic inclusions were identified by metallographic, X-ray microspectral and petrographic methods, see [1]. Distribution of elements and nanohardness of steel matrix near inclusions were determined.

3. Results and discussion. Most of inclusions of "eutectics" are low-melting and both their phases must to melt almost simultaneously. But eutectics with high-melting phases exist too, see [1]. Inclusions of eutectics are differed from heterophase non-metallic inclusions "high-melting phase surrounding with low-melting cover" and "phases are beside" with the presence of more dispersed phases and more branching net of interphase boundaries eu1↔eu2 inside inclusions. Molten inclusions "eutectics" is been in molten steel matrix and micrometallurgical bath is formed. Hydrodynamics flows in the conditions of vortex thermocapillary mixing and temperature gradients are origined and that causes displacement of inclusion phases. In the result of high-speed melting of inclusions "eutectics" heavy oversaturated liquid solution or two liquid solutions on the base of inclusion and steel matrix differing by concentration heterogeneity are formed. In such liquid systems nonbalanced mass transfer is happened that suppresses of cooperative growth of phases and formation of cooperative structures of non-metallic inclusion.

Evidently under laser melting and contact interaction of eutectic inclusion with liquid steel matrix advantageous the dissolution (melting) of interphase boundaries eu1↔eu2 must to happen. Just distribution of surface tensions in the zone of contact interaction when heavy disordered state in surface areas of eutectic phases is created and diffusive composition equalizing do not happened the heavy nonequilibrium conditions and thermodynamic stimulus for rapid simultaneous or selective dissolution of phases of inclusion are appeared. Besides since speed of mass transfer and degree of saturation of eutectic phases with elements of steel matrix (in first turn with iron) is different. That phase of inclusion with more degree of saturation by iron is dissolved more quickly.

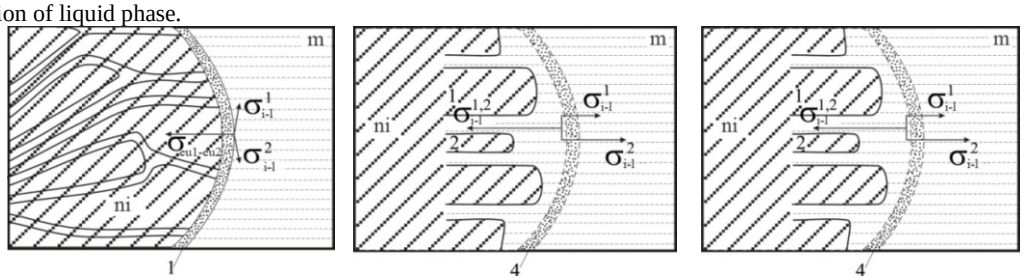
Inclusions of "eutectics" containing both low-melting and high-melting phases after high-speed crystallization in the conditions of laser action were investigated. They had regular colony structure in the initial state. In the most of them such structure was not kept after laser action. Evidently transformation of type of eutectic was happened. Regular colony structure was transformed into abnormal eutectic without regular distribution of components (Fig. 1, a, b). According to reference, see [2], abnormal eutectics are formed in conditions when conjugational growth of crystals of eutectic phases do not possible and also when eutectic is formed with high-entropy phases. It is evidently the absence of possibility for conjugational growth of crystals of eutectic phases in the conditions of laser action. For the structure of abnormal eutectics the presence of phase areas with different shape chaotically disposing in inclusion is typical. Abnormal eutectic structures after laser action with energy of impulse W_{pulse} 10 – 25 J were observed. In the resort of W_{pulse} 30 J together with abnormal eutectics the sulphide and silicate eutectics inclusions with amorphous structure were observed. Some inclusions have signs of colony structure (Fig. 1, c). Various of structures of inclusions of "eutectics" is explained with differences of nature of eutectic phases and also with heterogeneity of laser radiation promoting appearance of different conditions of their crystallization. Steel matrix under laser melting is saturated with elements of phases of inclusions of "eutectics" independently on the type of inclusion.

a b c

Figure 1. Dissolution and melting of heterophase non-metallic inclusions of "eutectics" under laser action; x2000

Contact dissolution and melting of phases eu1 and eu2 of inclusions "eutectics" and also of interphase boundaries eu1↔eu2, eu1↔m, eu2↔m in molted steel matrix in nonequilibrium conditions under laser action is energetically excused because surface layers of both phases of inclusion being in stress state with high energy are replaced with liquid phase with less energy. Decrease of surface energy owing to contact interaction of eutectic phases and steel matrix and also owing to interaction of phases eu1 and eu2 of inclusion in the moment of melting is rather considerably that system "phase eu1 of inclusion" – "boundary eu1↔eu2" – "phase eu2 of inclusion" – "interphase boundaries eu1↔m, eu1↔m" – "steel matrix" was thermodynamics instable after laser action. Realization of such mechanism of melting and dissolution of inclusions of "eutectics" is determined with value of stresses creating in surface layers of both phases of inclusion. Evidently owing to formation of big stresses in surface layers of matrix and both phases of inclusion "eutectics" in the conditions of high-speed laser action it is possible nonactivated transformation of heavy disordered surface layers of both phases of inclusion into liquid state with formation of liquid phase.

Consistency of formation of heavy disordered areas on the surface layers of both phases of inclusion "eutectics" and also movement of interphase boundaries is shown on Fig. 2. In the moment of melting (dissolution) of eutectic type of inclusions the both their phases must to dissolve practically simultaneously. Evidently owing to contact interaction of inclusions with liquid steel matrix advantage melting (dissolution) of interphase boundaries of eutectics takes place. On Fig. 2 surface tensions on interface boundaries are shown. Distribution of surface tensions in zone of contact interaction then heavy disordered state in surface areas of eutectic phases is formed and diffusive equalizing of composition do not has time for happen the heavy nonequilibrium conditions are created and thermodynamics stimulus for rapid simultaneous or selective dissolution of inclusion phases is appeared.



a b c

Figure 2. Schemes of laser melting of inclusions of "eutectics": $\boldsymbol{\sigma_{i\text{-}l}}$ – stresses on boundary between hard heavy distortion area of inclusion and liquid steel matrix, $\boldsymbol{\sigma^{1,2}_{i\text{-}l}}$ – stresses between eutectic inclusion and molten steel matrix, $\sigma^{1}_{i\text{-}l}$ and $\sigma^{2}_{i\text{-}l}$ - surface tensions between phase eu1 and phase eu2 of inclusion and molten steel matrix accordingly, $\sigma_{eu1\text{-}eu2}$ - surface tensions between phase eu1 and phase eu2 of inclusion, $\sigma^{1,2}_{l\text{-}l}$ - stresses between molten eutectic inclusion and molten steel matrix, 1 – inclusion-matrix boundary, 2 – initial position of inclusion-matrix boundary

Under quenching from liquid state in both phases of inclusion the zones of high-speed crystallization with columner shape of grains and liquation are formed. Silicate and sulphide inclusions of "eutectics" were inclined for amorphization.

Analysis of oversaturated areas of steel matrix near non-metallic inclusions was shown that their structure is heterogeneous. There are a few versions of their structure revealing owing to heat etching under laser action. It may be one zone, or two zones, or three zones. In non-metallic inclusions the surface zone may be absebt or may be one zone or two zones. Quantity of oversaturated zones in steel matrix did not depends on the type and state of non-metallic inclusions in the moment of laser action but depends on the regime of laser treatment: when impulse energy was higher and action time was bigger the tendency of multy-layers forming was bigger too. This is caused with activation of mass transfer owing to the rise of energy of laser impulse and increase of possibility of its realization at increase of the action time. Oversaturated areas of steel matrix near non-metallic inclusions are differed with distribution of chemical elements. At presence of one oversaturated zone near inclusion the gradual decrease of quantity of elements of non-metallic inclusion with removing from the inclusion was observed. At presence of the two or three oversaturated zones in each of them the gradual decrease of quantity of elements of non-metallic inclusion with removing from the inclusion was observed but quantity of elements in the second zone was less then in the first zone and also quantity of elements in the third zone was less then in the first and second zones. Thus at presence of a few oversaturated zones in steel matrix the cascade of elements concentration in zones of interaction between inclusion and steel matrix with gradual decrease of the quantity of elements in each zone were observed (Fig. 3, a - d).

Near inclusions of "eutectics" the formation of saturated zones of steel matrix is controlled with both phases eu1 and eu2 which are the sources of alloying of steel matrix and are differed from the heterophase non-metallic inclusions "high-

melting phase surrounding with low-melting cover" and "phases are beside" with more degree of dispersivity (Fig. 3, c). In the results near inclusions of "eutectics" with regular colony structure or structure of abnormal eutectic the composite liquation zones of a few types are formed: the cascade type of layer composites with "splashes" of quantity of elements passaged from the phases of eutectic; the layer-"spot" type of composite with columnar or "tunnel" structure and "splashes" of quantity of elements passaged from the phases of eutectic; dispersed type that connects with formation of "satellite" particles; complicated layer-dispersed composite with cascade distribution and "splashes" of quantity of chemical elements. Characteristic sign of saturated zones is high degree of dispersivity of the phase and structural components and also presence of the "splashes" of quantity of elements passaged from the phases of eutectics. In addition to the saturated zones of the "spot" and layer-dispersed types have other morphology namely columnar or "tunnel" character connecting with presence of initial dispersed directed colony structure of eutectics.

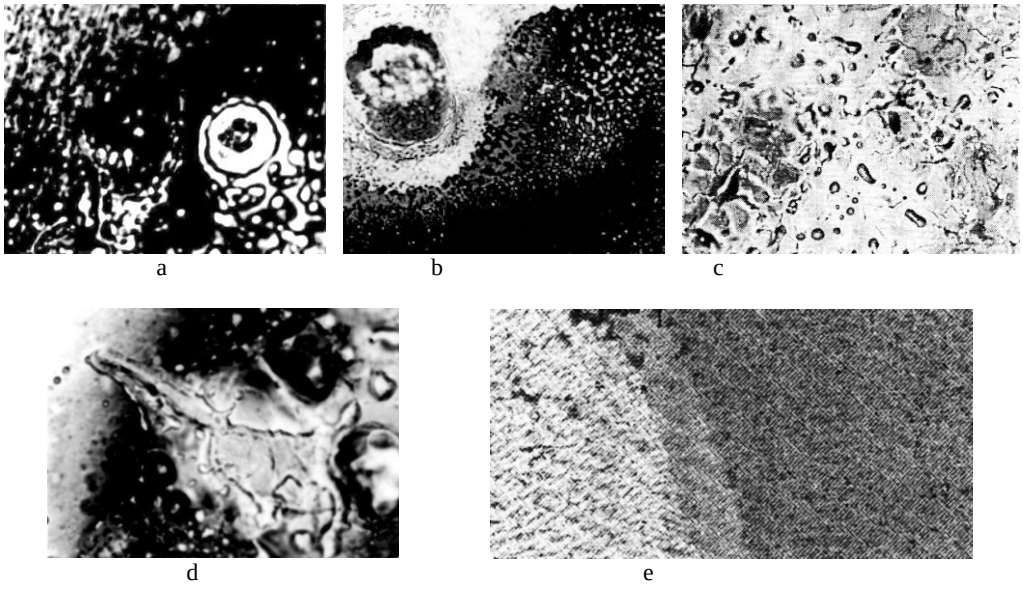


Figure 3. Zones of interaction between heterophase non-metallic inclusions and steel matrix under laser action: a – d - x500x6

4. Conclusions. Mechanism of melting of eutectic non-metallic inclusions and inclusion-matrix boundaries under contact laser melting with steel matrix in the conditions of abnormal mass transfer connecting with formation of zones with high dislocation density and also with electron and electro-magnetic interaction between inclusion and steel matrix was proposed. That allows to create the possibilities for the influence on the inclusion-matrix boundaries and also on the chemical and phase composition of surface layer of non-metallic inclusions. Peculiarities of structure of non-metallic inclusions after speed crystallization were investigated. And also the peculiarities of formation of the contact interaction zones in steel matrix in the conditions of abnormal mass transfer from inner sources (non-metallic inclusions) under laser treatment were investigated. These zones connecting with origin of the liquation strengthened areas represent different types of composite layers. Gradiental zones with cascade and "spot" distribution of elements and nanohardness, dispersal zones with different types of strengthened microphases and nanophases, "tunnel" zones, and also zones with combine structure were formed. Melting of inclusions under laser action is corresponded with change of their structure and phase composition.

5. Literature.

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