Journal of Siberian Federal University. Engineering & Technologies 4 (2009 2) 376-383
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УДК 539.213.536.42

The Structure and Magnetic Properties of Fe-Mn-C Alloy

Vera V. Kazantseva and Ludmila I. Kveglis*
Siberian Federal University,
79 Svobodny, Krasnoyarsk, 660041 Russia [1]

Received 16.11.2009, received in revised form 03.12.2009, accepted 18.12.2009

The structure of intergranular borders in Fe-Mn-C alloy has been investigated. Importance of Fe-Mn-C alloys researches connecting with their wide use in machine industry as constructional materials. In this work an attempt to find out the physical nature of high shock viscosity of Fe-Mn-C alloy, mechanical and magnetic properties, calculation of intergranular borders electronic structure is made.

Keywords: alloy, austenitic steel, nanocrystalline magnetic films, magnetization of saturation, structure of Frank-Kasper, crystallization, viscous tension, density of packing, plastic deformation, local electron structure, deformation, quasicrystall, grain, invar, intergranular borders.

1. Introduction

The alloy of $Fe_{86}Mn_{13}C$ structure is known as Hadfield steel (110G13L). The given steel is widely known as a material that undergoes self-hardening under action prolonged dynamic shock deformation. The physicochemical nature of this process till has not been understood.

The purpose of work is an attempt to explain a change of magnetization from the point of view of structure intergranular borders in austenitic steel (manganese steel). At this time remain not discusses following problems:

Investigation of intergranular, interboundary layer in $Fe_{86}Mn_{13}C$ alloy with invar consistent in massive and thin film samples.

Analysis of structural and magnetic transformations in alloys with invar consistence.

To construct the local electron structure of $Fe_{86}Mn_{13}C$ alloy using scattering wave cluster method with the purpose to give a qualitative explanation of steel magnetic properties at prolonged dynamic shock deformation.

In the present paper the observation microstructure of region phase transition from FCC austenitic $Fe_{86}Mn_{13}C$ steel to FK12 + FK14 type of Frank-Kasper tetrahedral close packed structure [1] are described. We used the methods of optical microscopy, electron microscopy, electron and X-ray-diffraction to investigate the transformation area. The tetrahedral close packed structure of FK12 + FK14 type arose in intergranular space (at grain boundaries) from initial austenitic steel as a result of prolonged dynamic shock deformation. The shock deformation of nanocrystalline material causes the gradient of temperature, gradient of pressure and gradient of

* Corresponding author E-mail address: kveglis@iph.krasn.ru

concentration and the movement of nanoparticle groups relatively to each other. As a result, re-organization of individual nanoparticles takes place. The phase transition resulted in the formation of pseudomonocrystals, both periodic and quasiperiodic can be observed in intergranular space. Localization of deformation in impact zone initiates the phase transitions similar to temperature transition and can initiate mechanochemical processes [1, 2], which take place with formation from initial austenitic phase of the following phases: martensite, carbide, and also Frank - Kasper structure.

2. Samples and investigation methods

We investigated samples of 110G13L steel obtained by heat treatment: before quenching to austenite from 1150°C with fast cooling in water from 1150 °C down to room temperature. Then samples were annealed at 800–850°C.

The composition of the $Fe_{86}Mn_{13}C$ alloy was monitored using spectral, X-ray spectroscopic fluorescent and chemical analyses.

The hardness was measured by the Brinell, the Vickers, the Rokvell methods after a dynamic load. The sample surface structure was investigated by optical microscopy and X-ray diffraction (XRD).

To explain the specific features of magnetized and nonmagnetized regions, we investigated the chemical composition using X-ray fluorescent analysis. The structure was investigated by XRD analysis; XRD patterns were interpreted using the standard international tables of the JCPDS International Centre for Diffraction Data, Card no. 01-1252.

The local coercive force of ferromagnetic phase arises in some regions of the sample was measured by the Kerr method.

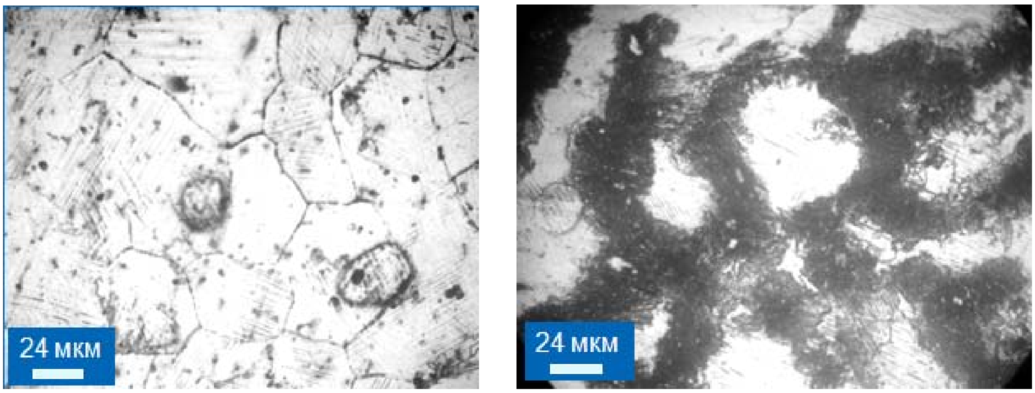
3. Experimental and result

The structure is forming at fast cooling in water, and possesses high viscosity and plasticity at enough good durability typical for austenitic steels. The hardness Brinell (the samples operated in a stone-grinder) exceeded 4000. The sample of Hadfield steel have been subjected to dynamic stressing 3000 kg on adjustment of hardness test by Brinell is shown on Fig. 1. Fig. 2 a, b shows micrographs of the steel surface before and after impact load.

Computer analysis of a grain size shows that a average grain ball is 4. The region with a defect structure is near the sample edge; it occupies about 1/3 of the sample area. Structure of samples after impact load in an operating mode of rock-crushing machine (the wide dark layers between light grains of austenitic have appeared) can be seeing on Fig. 2,b. The Vickers microhardness analysis showed that the grain boundary microhardness is 4830 mPa, while the microhardness of the main austenite grain is 3460 MPa. After impact load the samples changed their magnetic state. The regions directly subjected to impact became magnetized. Strain-induced martensite was found in the Hadfield steel and described in [3, 4].

In researching the chemical composition massive samples of $Fe_{86}Mn_{13}C$ X-ray fluorescent analysis no differences in the chemical composition have been identified. XRD analysis has shown appearance the martensitic phase reflections with a bcc lattice, additional reflections were found. Austenite grain boundaries exhibit inclusions of a phase having a tetrahedral closepacked Frank–Kasper structure FK12 + FK14 [5]. The XRD analysis showed that the intensity of the 331 and 222 reflections from some

Fig. 1. The Illustration of Hadfield manganese steel sample that have been subjected to dynamic stressing 3000 kg on adjustment of hardness test by Brinell



a b

Fig.2. Optical micrographs of the structure of surface of a 110G13L steel samples before (a) and after (b) dynamic load

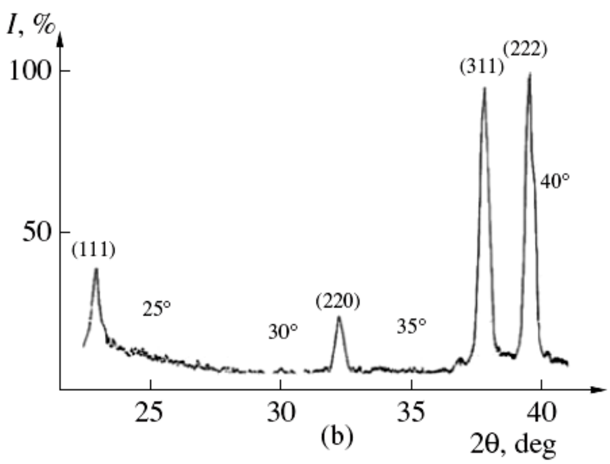


Fig.3. XRD patterns of (a) some regions of impact deformed 110G13L steel

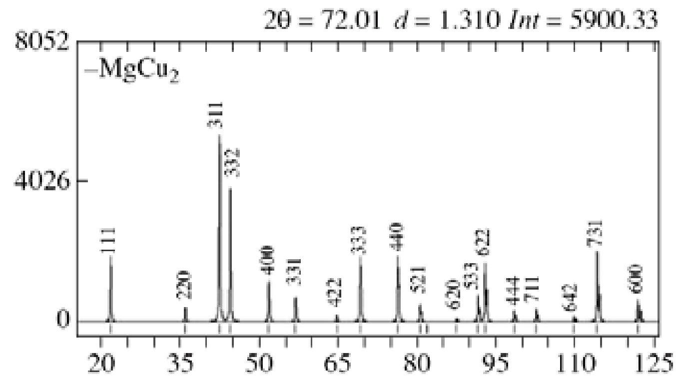


Fig.4. XRD patterns of $MgCu_2$ structure

sample regions is much higher than the 111 reflection intensity. This difference can be identified by comparing the obtained XRD pattern (Fig. 3) with the patterns of Frank–Kasper structures [5].

Fig. 4 shows the diffraction pattern for the $MgCu_2$ structure, which is of the Frank–Kasper type. It can be seen that the 311 and 222 reflections are stronger than the 111 and 220 reflections (Powder Diffraction File (JCPDS International Center for Diffraction Data, Swarthmore, PA), Inorganic, card 01-1226).

The most important features of $Fe_{86}Mn_{13}C$ alloys are high impact strength (resistance to dynamic loadings over 300 MPa) and invar effect (independence of linear expansion factor from temperature from -100 up to +250 °C). Strong dependence of substance magnetic properties on the character of interaction between microparticles results in the fact that the same substance (a constant chemical compound) at various temperatures, pressure, crystal or phase structure can be in various magnetic conditions. The deformation arising in ferro- and ferrimagnetic states at imposing of external mechanical pressure can cause change of the elasticity module by locating these bodies in a magnetic field. Changes of local magnetization were estimated by Kerr's method. Measurement of coercive force by induction method far from loaded area is illustrated on Fig. 5, in loaded area - on Fig. 6. In the printed area from initial austenitic phase with the FCC-lattice, mechanical synthesis with formation of Frank-Kasper structures has taken place.

Using the X-ray diffraction analysis, as it can be seen, that the X-ray diffraction pictures produced from an austenitic grain of the surface of steel 110G13L sample (Fig. 7), - matches to FCC structure.

Diffraction pictures of Hadfield manganese steel produced from intergranular layers, at scanning a sample's surface by X-ray beam is presented on Fig. 8. For diffraction pictures analysis we used results from the articles [5], [6].

To explain the magnetization nature of the sample consisting of austenitic grains and intergranular layers, which have Franc-Kasper structure FK12+FK14 typical to β-Fe-Mn, local electron structure has been investigated. The local electron structure of FK12 and FK 14 clusters have been studied by the method of self-consistent field [7, 8] to understand the nature of non-zero magnetization of $Fe_{87}Mn_{13}$ alloy exposed by shock deformation. For this purpose two cluster elements of a β-Fe87Mn13 cell have been chosen. These cells differ from each other by structure and number of atoms: 13 (FK12) and 15 (FK14) according to Frank-Kasper β-Fe-Mn type structure. Densities of spin-polarized electron states of chosen nanoclusters, produced by self-consistent field method are shown on Fig. 9 and Fig. 10.

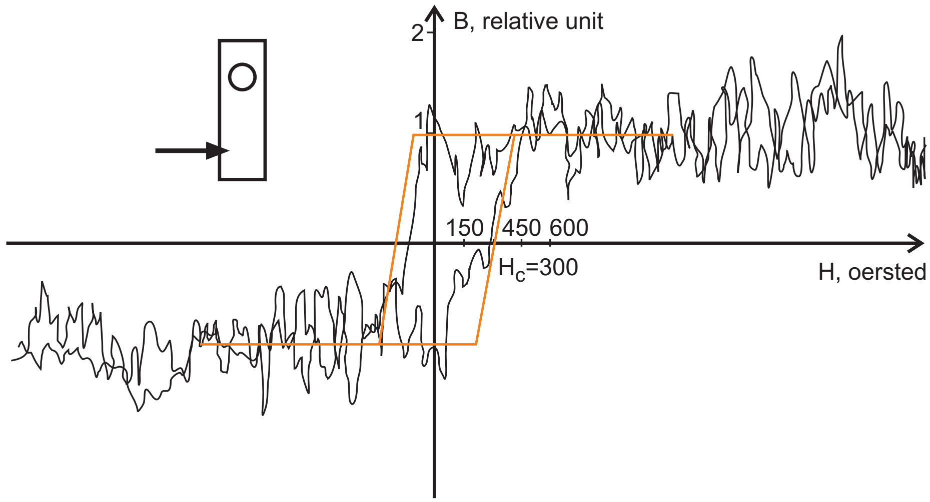


Fig.5. Measurement of coercive force loop far from marked area

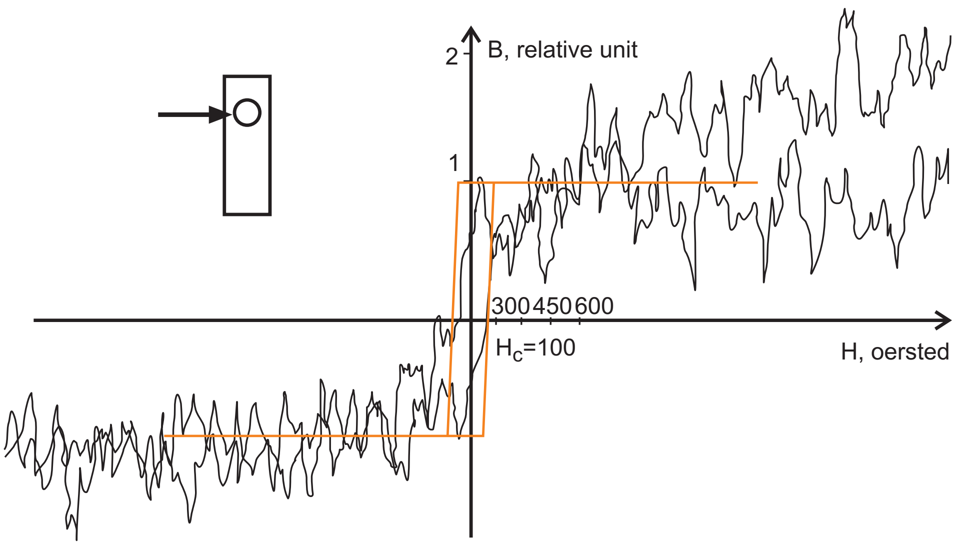


Fig. 6. Measurement of coercive force loop near from marked area

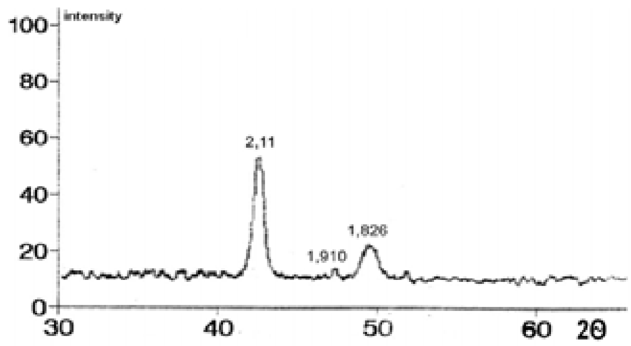


Fig. 7. X-ray diffraction picture of Hadfield manganese steel austenitic grain

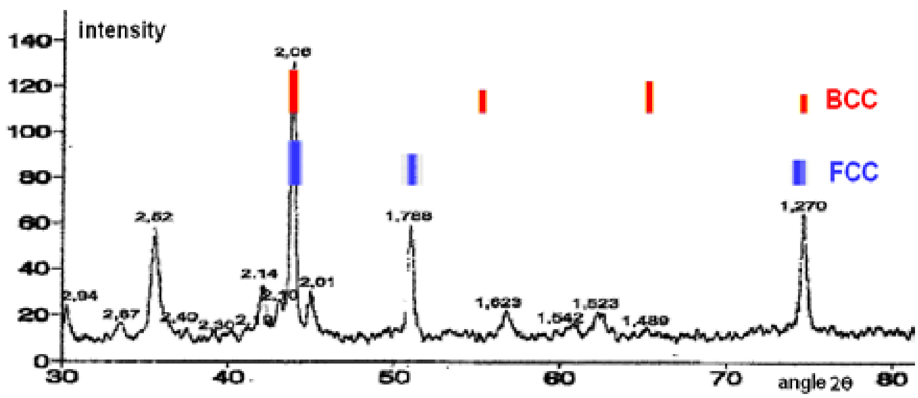


Fig. 8. X-ray diffraction picture of Hadfield manganese steel produced from intergranular layers, at scanning a sample's surface by X-ray beam

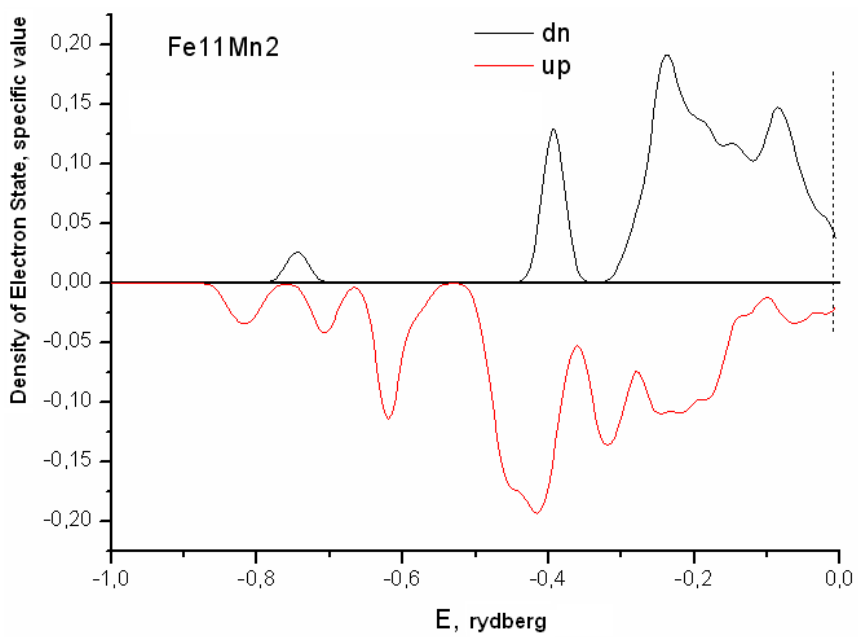


Fig. 9. Densities of spin-polarized electronic states of chosen nanocluster FK12, received by self-consistent field method are shown

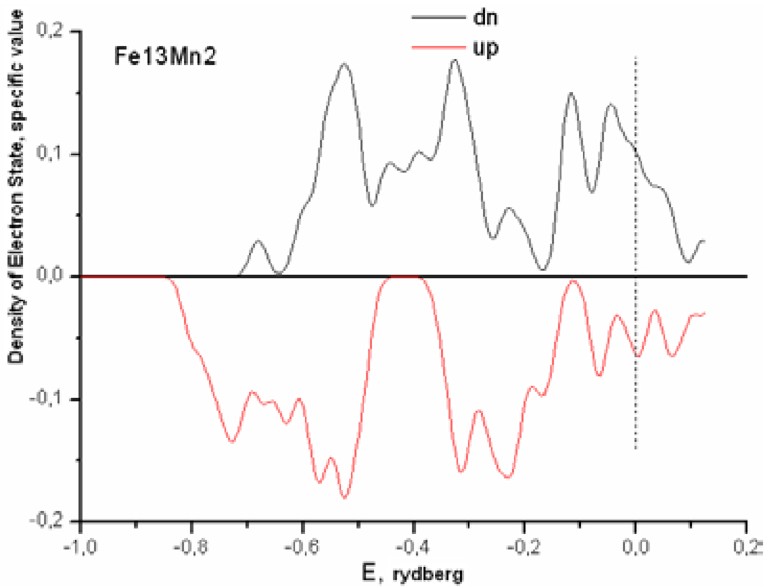


Fig. 10. Densities of spin-polarized electronic states of chosen nanocluster FK14, received by self-consistent field method are shown

Difference in cluster structure and, as a consequence, in potentials of their atoms and wave functions - results in the different magnetic moment in local areas of β-phase. We have found out that the difference of the FK12 and FK14 cluster structure results in the different magnetic moment clusters. The spin-polarized calculation shows the value of magnetic moment $<\mu>=1.4\mu_B$/at in case of FK12 cluster and $<\mu>=0.5\mu_B$/at for FK14 cluster.

4. Discussion

Are known to strains trigger chemical reactions. This fact is very important: as mechanochemistry is based on strain-induced chemical reactions (see Gilman J.J. [9]). The observed phase transition is accompanied by the appearance of non-zero magnetization, whereas austenitic $Fe_{86}Mn_{13}C$ steel is compensated antiferromagnetic. The d-phase of martensite was not found in this structure.

In our opinion, there are sufficient reasons exist to consider that the features of phase transition processes in localized regions of metal alloy with a self-assembling structure can be described in the framework of the modern shear transformation zone theory based on the excited-atom model [10, 11]. This theory asserts that macroscopic deformation in non-equilibrium material is a result of local rearrangements due to the cooperative motion of molecules in mesoscopic domains. Plastic flow appears due to the creation and annihilation of the transformation zone which velocity depends linearly on strain. Frank-Kasper structure can be formed as result of shear transformation zone movement in interborder layers [11]. As a result of tetrahedrally-close packed structures formation can appear quasi-crystal phases.

5. Conclusions

The current findings our research add substantially to our understanding the physical nature of high shock viscosity of Fe-Mn-C alloy. The results of this investigation show that:

1. In Fe-Mn-C alloy with invar consistent (Hadfield manganese steel) of bulk and film states the interboundary layers, which have Frank-Kasper structure FK12+FK14 of β-Fe-Mn type was founded.

2. Magnetic characteristics of both bulk and film states of alloys spontaneously change under action of dynamic stressing.

3. The local electronic structure speculative analysis constructed by scattering waves method, qualitatively explains of magnetic properties at mechanical stressing of $Fe_{87}Mn_{13}$.

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Структура и магнитные свойства сплава Fe-Mn-C

В.В. Казанцева, Л.И. Квеглис
Сибирский федеральный университет,
Россия 660041, Красноярск, пр. Свободный, 79

Исследована структура межзеренных границ в сплаве Fe-Mn-C. Важность исследования Fe-Mn-C сплавов связана с их широким использованием в машиностроении как конструкционных материалов. Делается попытка объяснить физическую природу высокой ударной вязкости сплава Fe-Mn-C, механические и магнитные свойства, расчет электронной структуры межзеренных границ.

Ключевые слова: сплав, аустенитная сталь, нанокристаллические магнитные пленки, намагниченность насыщения, структура Франка-Каспера, кристаллизация, вязкое течение, плотность упаковки, пластическая деформация, локальная электронная структура, деформация, квазикристалл, зерно, инвар, межзеренные границы.