Structure Transformations and Increasing of Mechanical Properties of Composites

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Summary: There carried out a study of regularities of deformation and fracture of the composite with structure-unstable binder, the peculiarities of inelastic behavior of the matrix having structural phase transformation. It was shown that there was formed the ultra-fine structure with typical size of crystallites less 10 nm having high plasticity and high capacity to hardening. This structural state of the matrix lead to the effective transmission of external loading to hardener and a dislocation slides even in typical brittle particles, for example, titanium carbide on a microlevel and rotation of the carbide particles on a mesolevel result in multiple cracking of a plastically deformed particles and, finally, to the high value of the fracture toughness. The material fragmentation on the fracture surface was founded, and the presence of transformation leads to the amorphisation of the fracture surface.

Keywords: structure transformations, composites, ultra-fine structure, plasticity, fracture.

INTRODUCTION

Composites with disperse hard particles being in a relatively soft metal matrix are special class of materials - so called hard alloys, which are widely used in engineering both as structural and cutting tool materials. Hard particles are increasing strength and hardness and a plastic matrix give rise to the high toughness and plasticity to the whole material. At low content the particles promote the higher yield stress of plastic deformation of a material (as carbides in steels for example). In other case the plastic matrix gives some plasticity and toughness to a brittle material, carbide, for example.

From all the existing models only some of them [1] pay a sufficient attention to a binding phase. Nevertheless, the problem becomes apparently principal firstly for physics of the deformation process of a such class of materials to be understood for correct modeling of mechanical behavior of such composites, and for increasing of the properties of the materials and new-generation composites with the highest properties to be worked out. The fact is that the non-uniform stresses in the disperse-hardened composite stipulate considerable mechanical constraint of deformation playing the leading part in the formation of the properties of these materials. Taking into account a rather small (less 1-2 μm) size of the interparticle distances and the higher yield stress of a matrix as a result of the lower thickness of interlayers, it's difficult to expect that dislocation sliding should be effective under these conditions.

So, it is necessary to look for new materials as the binding phases that should provide the effective deformation of the composite under strained conditions and preserve its fracture as a result. In our previous work [2,3] it have been shown, that the usage in a composite as binder of an alloy with structure transformation permits the essentially to increase its mechanical properties. The alloys with thermoelastic martensitic transformation may be taken to materials of such a class owing to their crystal structure instability with respect to shear, for example, NiTi [3].

The main purpose of the work is to study a structures at a various scale levels, the phase composition, the deformation processes and fracture of TiC - TiNi composites with a structure-unstable binding phase.

THE EXPERIMENTAL PROCEDURE AND MATERIALS

The TiC-TiNi composite with martensitic transformation in binder was investigated. The material was obtained by powder metallurgy methods [4] and were a cylinder form with the size 10*10 (mm), which were used for different types of loading. After loading analysis of its microstructure by the X-ray and TEM was carried out.

RESULTS AND DISCUSSIONS

On Fig.1 are shown stress-strain curves for quasi-static loading for stable and unstable states of binders in composites. As one can see, in the second case the plasticity is higher then in stable state of binder.

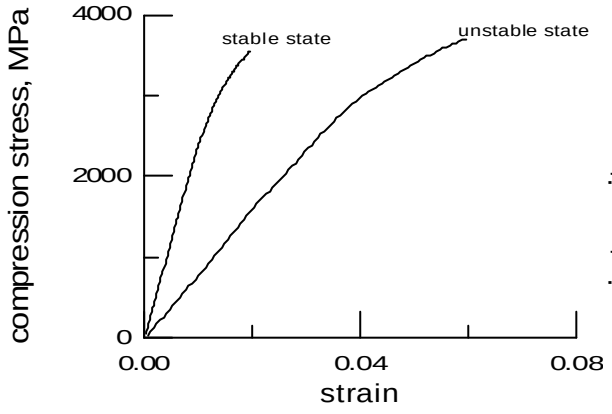

Figure 1. Stress-strain curves for TiC - 40% TiNi composite

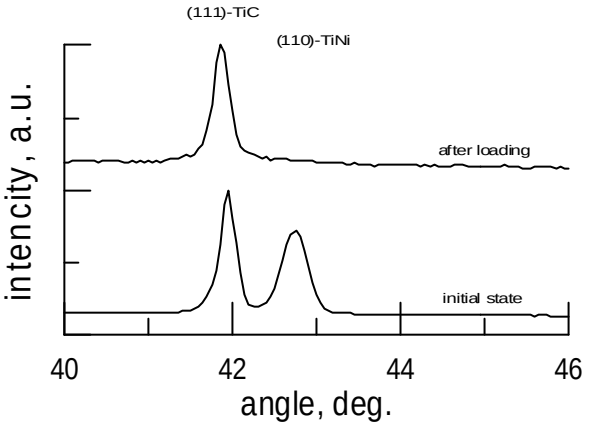

Figure 2. The X-ray patterns of samples, CuKα.

On Fig.2 are shown the X-ray patterns, obtained in initial condition and from fractured surface. As one can see, after loading to high strains X-ray reflections, belonging to a binding phase are not practically visible, while reflections of carbide has a broadening. Such kind of X-ray lines permits to make the conclusion, that in volume of a binder material the amorphous structure were formed.
For analysis of an internal structure of such material after loading the researches on thin foils, cutting from fractured samples were carried out by TEM investigations.
The investigations of deformation and fracture processes of TiC-NiTi alloys with the structure transformation showed for NiTi deformation to be accompanied by considerable changes of structure state when being lost shearing stability of its lattice. Already in the non-deformed TiC-NiTi samples the NiTi structure is inhomogeneous to a high degree. One can observe the characteristic rippled contrast on the light-field TEM patterns what testifies to NiTi pre-transition state. Under loading still in a region of the composite elasticity NiTi the microstructure changed from a disperse domain into a banded contrasting one that is characteristic for the intermediate shear structure. Firstly, one can observe generation of diffusion peaks in the electron diffraction patterns and then extra-reflexes both in commensurable and incommensurable positions with the different parameter of commensurability in the different directions of axes of the reciprocal lattice, what testifies to several variants of the martensite domains each being generated with its own real structure. A such character of NiTi transformation is caused by highly inhomogeneous state arising near the hard particles of the composite under loading. Under the conditions of high stress gradients appearing in a matrix, the directions of atomic displacements in microzones stipulating local losses of B2 structure stability are

determined by stressed states arising under loading at a moment in a given microvolume of the binding. These conditions determine the orientation of newly generating martensite domains too.
NiTi transformations of such a character results in simultaneous decrease of the peak and the integral intensities of B2-phase lines in X-ray patterns not being accompanied by growing or arising new martensite peaks. One can only observe the diffusive of the most intensive lines of monoclinic NiTi in unidiffusive peak, what is characteristic when being generated a fine-disperse structure.
Under higher deformation in zones of the binding being under the most stressed conditions, there appears a disperse structure consisting of disoriented fragments of B2 phase and martensite domains. The electron diffraction patterns, taken from these zones have a characteristic ring shape of a different kind, mainly rings of point peaks and separate arcs arranged in one azimuth range of the wide (110) B2 ring against the weak diffuse (110)-B2 background. One can see the wide, highly intensive ring sharply standing out the others and being 0.201-0.240 nm in width corresponding to an interval of the interplanes distances. One can see the most intensive (002), (111), and (020) peaks of a monoclinic phase and (110) peak of B2 cubic structure. Moreover, one frequently meets with electron diffraction patterns being rings of point peaks with reflections of B2 and martensite structures against the background of diffuse (110) ring of B2. Second-order peaks are weekly distinguishable. Under deformation to considerable degrees there are observed in separate zones of the composite binding (preferentially in the vicinity of intercarbide boundaries and with continuous (110) diffuse rings of B2 and rare arcs in the main azimuth directions. Diffraction of a such character corresponds to quasiamorphous state, Fig.3.

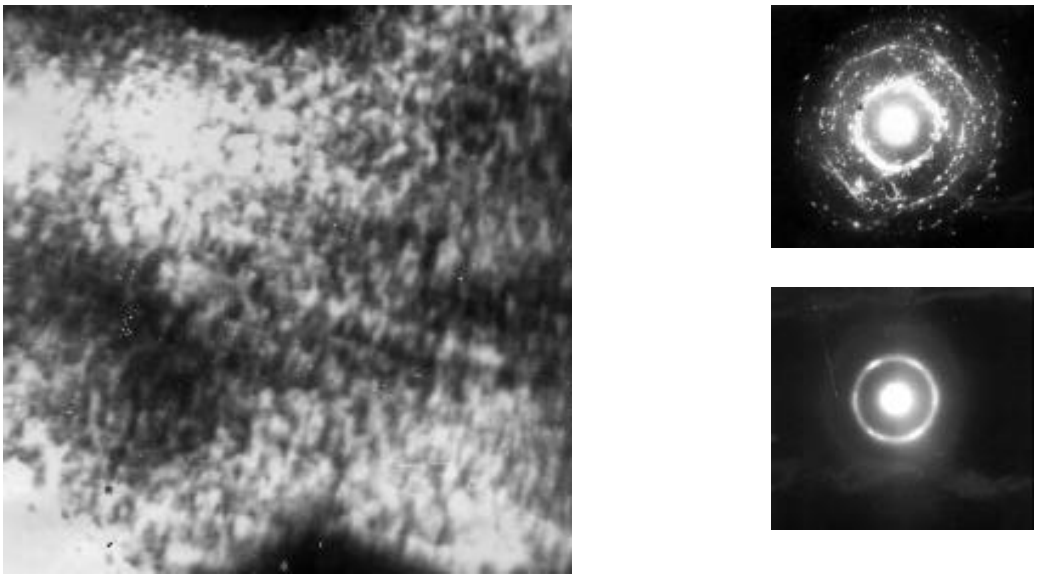

Figure 3. TEM image of binder (left), electron diffraction of deformed binder in composite and the quasi-amorphous state of a binder

On Fig.4 the angles measured on the various images of contact "martensitic plate - carbide grain" are shown. It is visible, that than it is less size of a carbide grain, that it is more angles of contact. It, as appear, testifies that in a loading process there is the rotation of the carbide grains that greater, than it is less their size.
Such rotation of the carbide grains cannot occur without formation of specific internal structure of a binding phase. On Fig.5 data on measurement of a azimuth angles of binder fragments from degree of plastic deformation are shown. It is visible, that the high-grained structure (for TEM) in initial condition is broken with growth of strain into fragments mis-orientation the friend concerning friend, and the angle of a mis-orientation is increased exponential with growth of deformation. It is characteristic, that in carbide grains the increasing of dislocation density were observed.

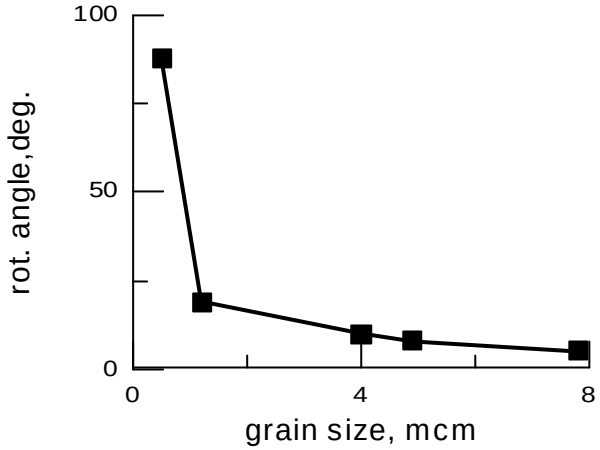

Figure 4. The rotation of the carbide grains vs. its sizes

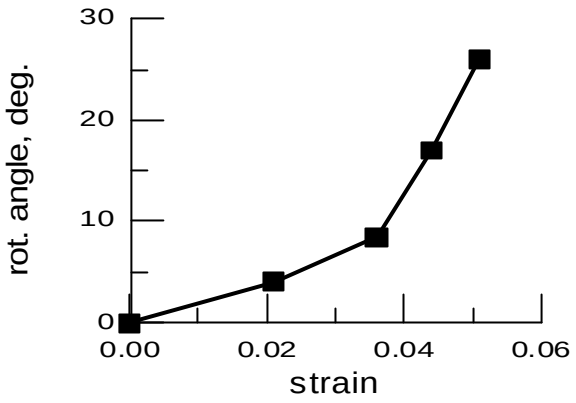

Figure 5. Angles between binder fragments vs. degree of plastic deformation of composite

So, it may be realized the following transformation scheme in the binder phase of the composite under deformation: B2 => B2 + B19' => B2 + "quasiamorphous state", with formation of fine-grain, highly disoriented structure less then 10 nm in grain size, characterizing by high plasticity and strengthening and stipulating external loading effectively transferred onto a strengthener, causing simultaneous dislocation slipping even in typically brittle TiC particles, Fig. 6.

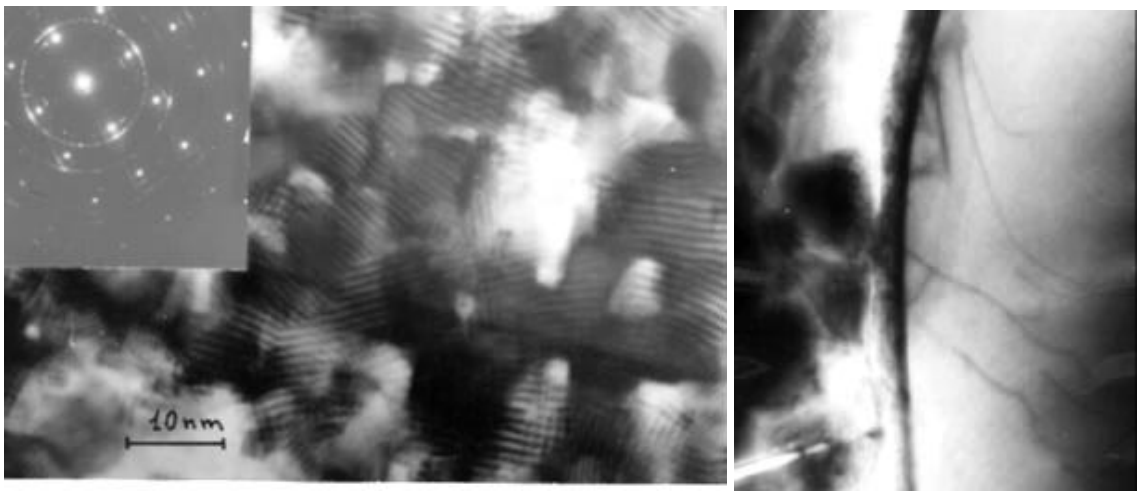

Figure 6. The TEM image of TiNi binder in composite after fracture and its diffraction patterns (left) and TEM structures of TiC particles. One can see dislocations after loading

Subsequent loading increase results in multiple cracking of plastically deformed particles and finally in high value of fracture toughness, continuity of the material being preserved.
On Fig.7 the bending strength and plasticity composite with ordinary and unstable binders vs. mass content of binder are shown. As one can see, if binder can undergo the phase transformation, composite has more high mechanical properties.

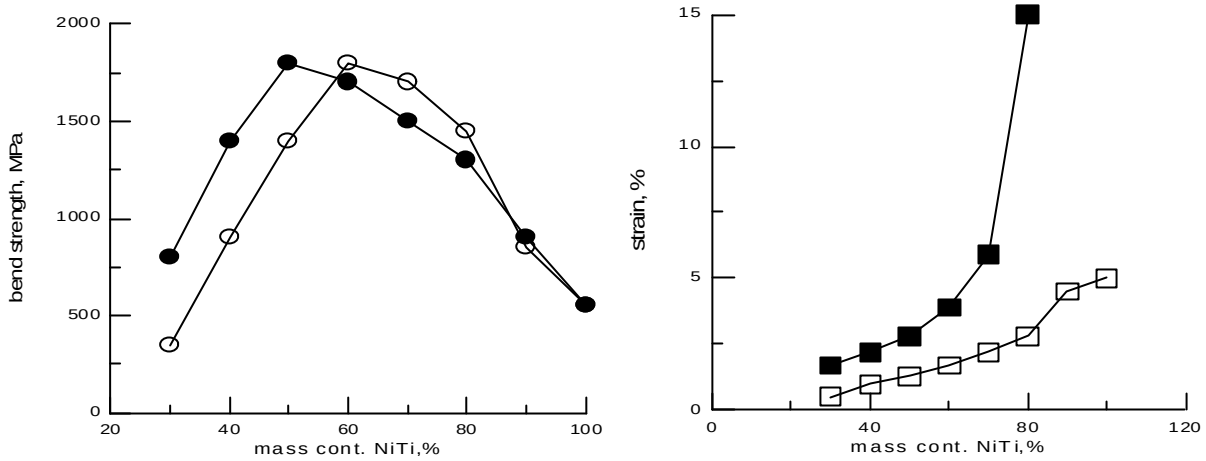

Figure 7. Bending strength and plasticity of composites with stable (open point) and unstable binder (black point) vs. mass. content of binders.

CONCLUSIONS

Thus, it is possible to point out a number of the main features of behavior of a composite with a structure-unstable binding.

1. Inhomogeneous deformation of the binding phase is able to change a structure under external loading causes its transformation. It should be noted for the latter to occur to the different degrees following the strain, the higher inhomogeneity of stressed state and plasticity of the binding material owing to transformation, the higher dispersion of the binding structure.
2. The combined influence of transformation and constraint of deformation results in the efficiently higher stress of martensite shear under deformation and in a binder arises the fine-grain structure that causes the high toughness of the whole composite.
3. The physical meaning of usage of the structure-unstable bindings in the composites is that to lower a scale of structure levels of plastic deformation and fracture owing to formation of a micro-crystal structure in the binding phase under inhomogeneous loading.
4. The our results have been demonstrated that the efficiently higher plasticity of an alloy can be achieved at the same level of strength due to the transformation of the structure-unstable binder, it being not important, in what way this is achieved - due to changing either of its composition or the deformation temperature. In any case the specific energy of plastic deformation increases approximately more than 3 times.

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