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Properties and Structural Transformations of Mgb_2-tapes under the Action of Plasma Shock Waves

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Abstract

The current-carrying properties (J_c, J_c (B)) of MgB_2 tapes are structurally sensitive parameters and significantly change during the deformation and compaction of MgB_2 interlayers. The grain size, morphology, phase composition, presence and size of structural defects play an important role in this process. All these factors can undergo significant transformation under the influence of plasma shock waves. The report presents the results of the shock waves impact generated on the plasma focus installation on the critical current of MgB_2 tapes in the longitudinal and cross sections with a change of energy and the number of pulses. The conducted studies showed the possibility of increasing J_c on 50% in magnetic fields up to 2-3 T. This effect is due to the refinement of grains and the compaction of MgB_2 interlayers.

Keywords: Superconductivity, MgB_2, plasma action, morphology, critical current.

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1. INTRODUCTION

Superconductivity at 39 K in MgB_2 has been discovered in 2001 and since then has caused serious interest [1]. Advantages of this compound in comparison with the known high temperature superconductors are connected with the simple hexagonal lattice in combination with the simple binary composition, relatively low cost of ingredients, lack of the problems related to the weak links on the grain boundaries, low anisotropy of the current and, the most importantly - a high current-carrying ability in external magnetic fields of 3-4 T [2-4]. All of these characteristics suggest the possibility of using this compound in sufficiently high temperature range 20-30K. The mechanism of superconductivity in this compound is considered to be electron-phonon [5] and the current-carrying capacity mainly depends on the structural-phase state (size and morphology of grains, the presence of point defects, the effective pinning centers and packing density in the superconducting layers) [6-9]. All of these structural factors can be transformed under the action of shock waves of plasma and as a result, the current-carrying capacity can be increased.

2. MATERIALS AND EXPERIMENTAL METHODS

Experiments to apply shock waves were performed on the "Plasma Focus" installation. Shock waves in it were generated when a plasma pinch strikes at the target material containing MgB_2 tape. The maximum energy stored in the capacitor accumulator reached 4 kJ. Energy in the plasma stream striking at the target was about 100 J. The time of the action on the target was 10^{-7}sec. An energy flux density on the target reached $\sim 2 \times 10^9$ W/cm^2 and the jet velocity of the plasma jet was $\sim 10^7$ cm/s.

Studies were conducted on 14-core commercial MgB_2 tapes produced by Columbus Superconductor Company (Italy). The samples of the tapes had the following dimensions: the thickness of 0.65 mm, the width of 3.75 mm and the length of 35-40 mm. The superconducting interlayers of MgB_2 were enclosed in the sheath of iron and nickel and containing the copper for stabilization of the superconducting state. The working chamber of the installation was filled of inert gas - argon (pressure of 1.5 Torr). The surface of the tapes test samples were protected from the direct thermal action of plasma with plates (0.2 mm thick) made of molybdenum, titanium, iron, copper and aluminum. In addition, for uniform distribution of energy from nonlinear shock waves over the surface of the sample, it was covered two-millimeter layer of epoxy. Samples were fixed in the steel ditch, in which the plasma jet went through the 10 mm hole in diameter. This installation allowed transferring the pressure and heating into the volume of the superconducting interlayers uniformly and protecting the surface of the samples from the temperature overheating. In case of MgB_2 tapes, the impact zone of shock waves was 10 mm along the length of the tape. The distance from the anode to the surface of the tapes was 25, 30, 35 and 40 mm. The number of impacts for all samples was the same (5 times). They were applied from one side of the samples. The time interval between the pulses was 1.5 min.

Critical currents of the samples in the initial state and after impacts were measured ate the International Laboratory of High Magnetic Fields and Low Temperatures (Wroclaw, Poland) in a Bitter magnet in cross and parallel magnetic fields in the range from 2 to 9 T at the temperature of 4.2 K and as well at NRC "Kurchatov Institute".

Studies of macro- and microstructure of the original tapes and tapes after plasma impacts were carried out in cross and longitudinal sections with different magnifications on the scanning electron microscope EVO-40 (ZEISS). The chemical composition of the superconducting MgB_2 interlayers in the volume and in the interface with the metal sheath (iron) was studied on the scanning electron microscope JSM-35 (JEOL) with a Link attachment. X-ray phase analysis was performed on Ultima IV diffractometer (Rigaku).

3. EXPERIMENTAL RESULTS AND DISCUSSION

Figure 1 shows the macrostructure of the cross and longitudinal sections of the tapes. In the middle of the tapes the copper layer is located, then the iron layer and outside the nickel layer arevisible. The MgB_2 layers are surrounded by iron and painted black but their thickness is not uniform both in the cross and in the longitudinal sections.

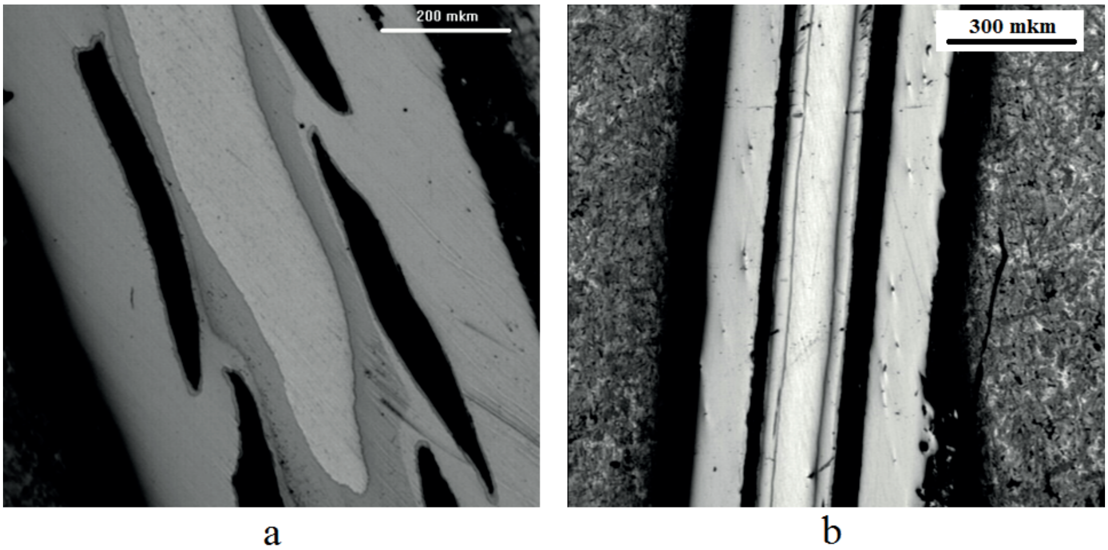


Figure 1: Macrostructure of the cross (a) and longitudinal (b) sections of the 14-core composite MgB_2 tape in the initial state.

An identification of structural components becomes more obvious when the structural components are colored (Fig. 2).

Comparison of the structure of MgB_2interlayers in the initial state and after plasma impacts (Fig.2 a-b), reveals the following differences: firstly, in the initial sample as well in longitudinal section as in cross-section during the grinding and polishing there is a noticeable deformation of the superconducting layer. And at the same time after the plasma impacts the boundaries superconductor - metal sheath (iron) are more even than in the initial state and the density of the superconducting layers is remarkably changed too.

Fig.3 shows the surface of the protective gaskets from iron, copper, titanium and aluminum after plasma impacts. It is seen that the surface of these plates after plasma impacts was experiencing a noticeable indentation but their integrity were preserving. At the same time an influence of pressure and temperature are noticeable, thereby

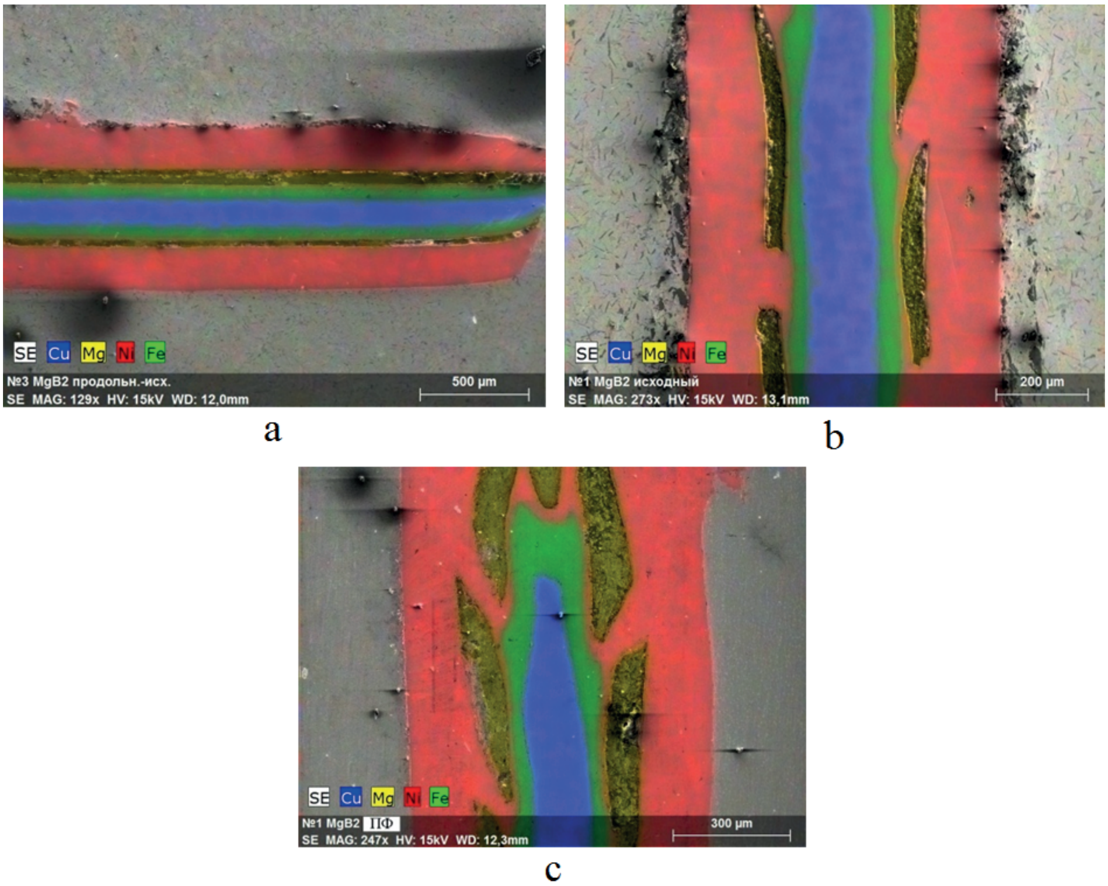


Figure 2: The macrostructure of longitudinal (a) and cross section of MgB_2 tape in the initial state (b) and after the plasma impacts (c).

these gaskets are important element for protection of the superconducting tapes surface. The outer surface of MgB_2 tapes with the change of the distance from the anode in the range from 25 to 40 mm were not significant changed, as well as the surface of the gaskets, the depth and diameter of the cavities. Thus, these gaskets are well suitable to protect the surface of the superconductors. However, their different thermal and mechanical properties (conductivity, heat capacity, strength) can influence at the structure, composition and superconducting parameters of the superconducting layers, subjected by shock waves. At this moment, different samples of MgB_2 tapes were processed by plasma impacts through different gaskets. But measurements of the superconducting properties of these samples have not yet been performed. This time we have full set of measurements of critical currents just on the samples processed by shock waves through the molybdenum gasket. Fig.4 shows surface of Mo gasket after impacts in the different conditions.

The distribution of Mg, Ni, Fe and Cu in the cross section of the tapes in the initial state and after processing by impacts is shown in Fig.5 and 6. It is seen that Mg in the interlayers are distributed inhomogeneously in both cases.

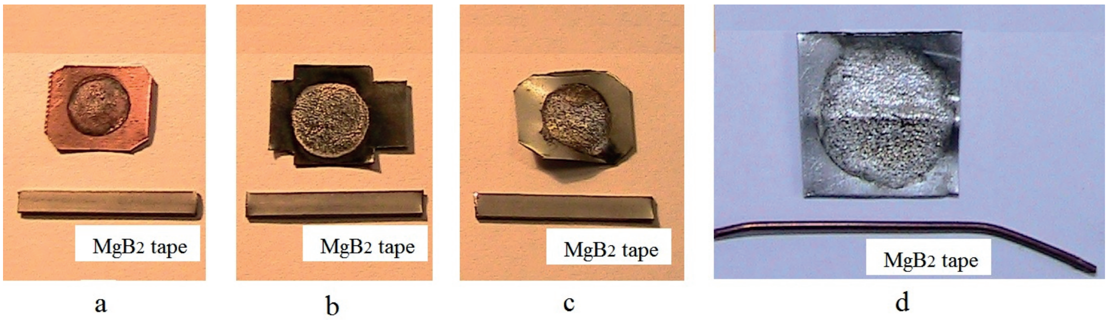


Figure 3: The surface of the gaskets from Cu - a, Fe-b, Ti-c, Al-d and the surface of MgB_2 tapes after plasma treatment (the distance from the anode = 30 mm, the number of strikes = 5).

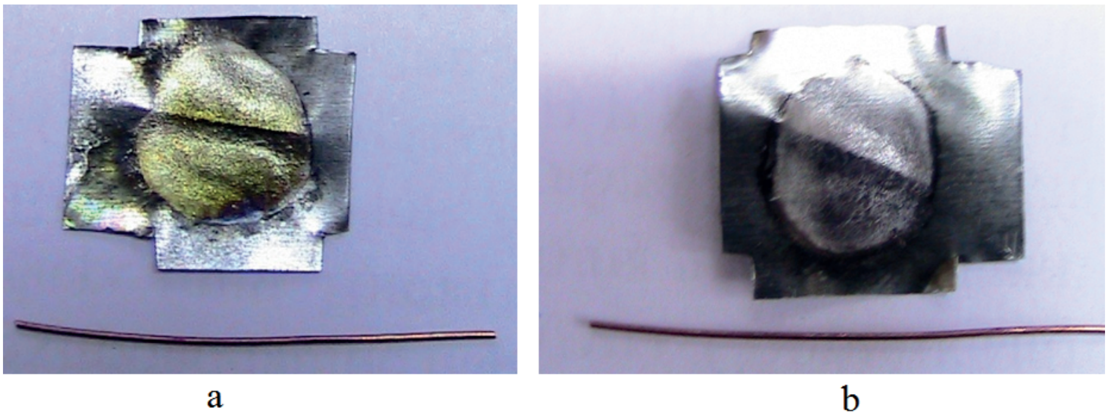


Figure 4: The structure of the surface of molybdenum gaskets after impact in the different conditions: a-6 mm from the anode, the number of impacts – 5, b- 18 mm from the anode, number of impacts – 3.

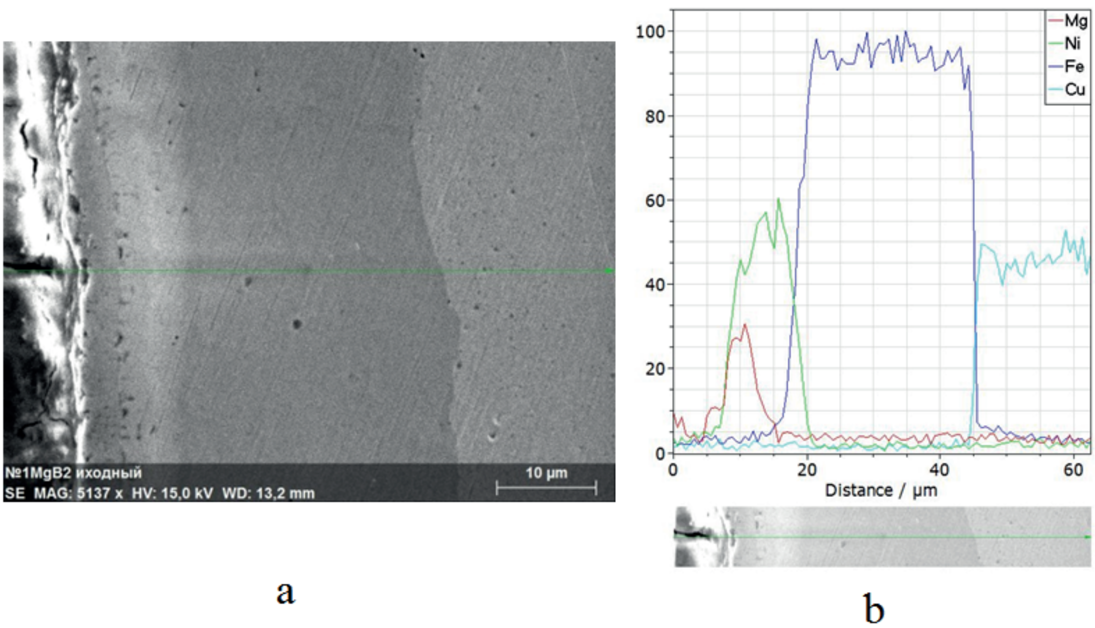
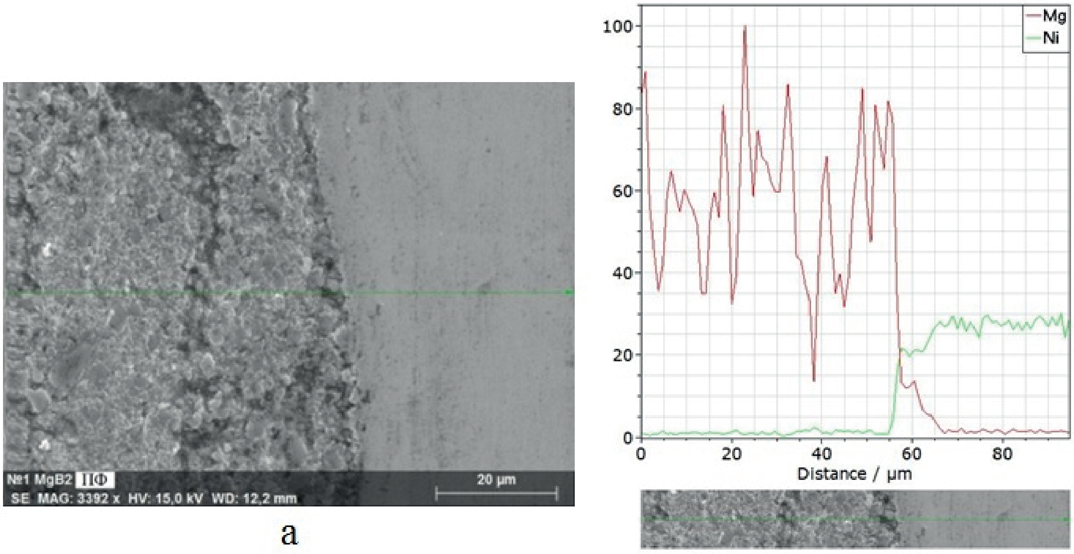
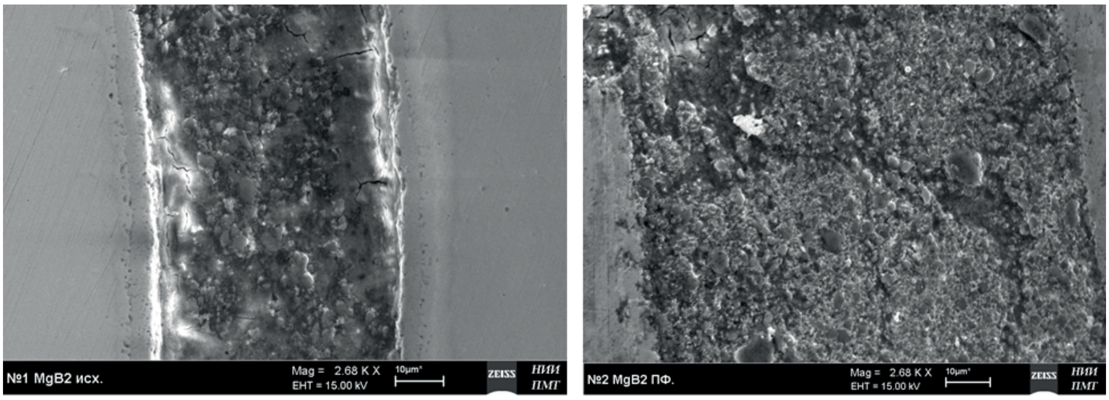


Figure 5: Microstructure of the cross section of the tape in the initial state (a) and distribution of Mg, Ni, Fe and Cu (b) in it..



a b

Figure 6: Microstructure of the cross section of the tape after impact – a. Distribution of Mg in MgB_2 interlayer and in the interface with Ni.



a b

Figure 7: Microstructure of MgB_2 layers in the initial state (a) and after plasma impacts at the distance of 30 mm.

The microstructure of MgB_2layers in the cross-section after the plasma impact processing is noticeably different from the microstructure of the original tape (Fig.7 a,b). In the original tape large blocks and cracks in the form of cross and winding cracks oriented across the superconducting layers were regularly observed. After the impact microstructure crushed several times (Fig.6b).

An average chemical composition of the interlayers in 5 different points in the initial state and after impacts at the distance of 30 mm (the number of impacts = 5) are presented in the table 1.

Significant changes can be noted. In the original tape, content of oxygen and carbon is higher than in the tape after impacts and the content of boron and magnesium is far from stoichiometric composition. After the shock-wave and temperature influence, the concentration of oxygen and carbon decreases noticeably, but the concentration of magnesium and boron increases. The composition becomes closer to the stoichiometric. These changes may cause an increase in the critical current.

Table 1: The chemical composition of MgB_2 layers in the original tape, and in the tape after plasma impacts (data averaged over 5 points in wt. and at. %).

Composition	B	Mg	C	O
In the initial state	13,06/17,67	24,78/14,92	36,27/43,92	25,87/23,48
After plasma impacts	37,32/48,82	27,32/13,69	26,26/30,44	9,09/7,44

Dependencies of *Jc* (*B*) in perpendicular (from 2 to 8 T) and parallel (from 4 to 9 T) magnetic fields are shown in Fig. 8a and b. The number of impacts was 5, the distance from the samples to plasma anode varied from 25 to 40 mm. The critical current in the initial sample in the magnetic field of 3T is 80 A, after impacts the current enhances above 140 A. In parallel magnetic field of 4 T, the currents are noticeably higher than in perpendicular field. Measurements of critical currents in the magnetic fields of 0-2 T were not possible to do because of limitation of the current source.

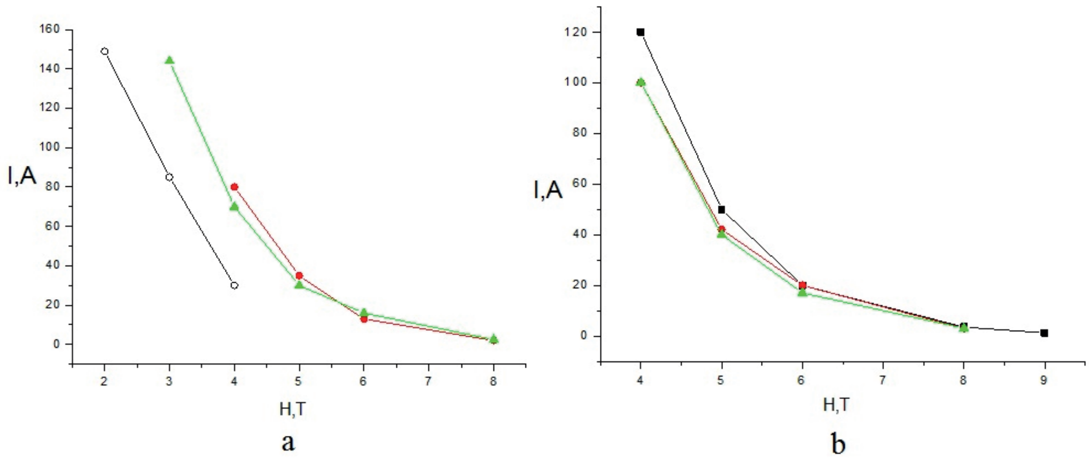


Figure 8: J_c (*B*) dependences in perpendicular (a) and parallel (b) magnetic fields for the MgB_2 tapes in the initial state (∘) and after plasma impacts at the distance of 25 (■), 35 (•) и 40 (▲). The measurements were carried out at the temperature of 4.2 K.

4. CONCLUSIONS

1. The possibility of the critical current increasing of MgB_2 tapes up to 50% in magnetic fields of 3-4 T due to the shock-wave and thermal action of the plasma is established.

2. The increase in the critical current of the tapes can be explained by an increase in the density and hardness of the superconducting layers, grain refinement, an increase of number of effective pinning centers, and a noticeable change of the chemical composition.

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