NSC “Kharkiv Institute of Physics and Technology”

Effect of thermomechanical treatment on the density and size of nanoscale precipitates in T91 steel

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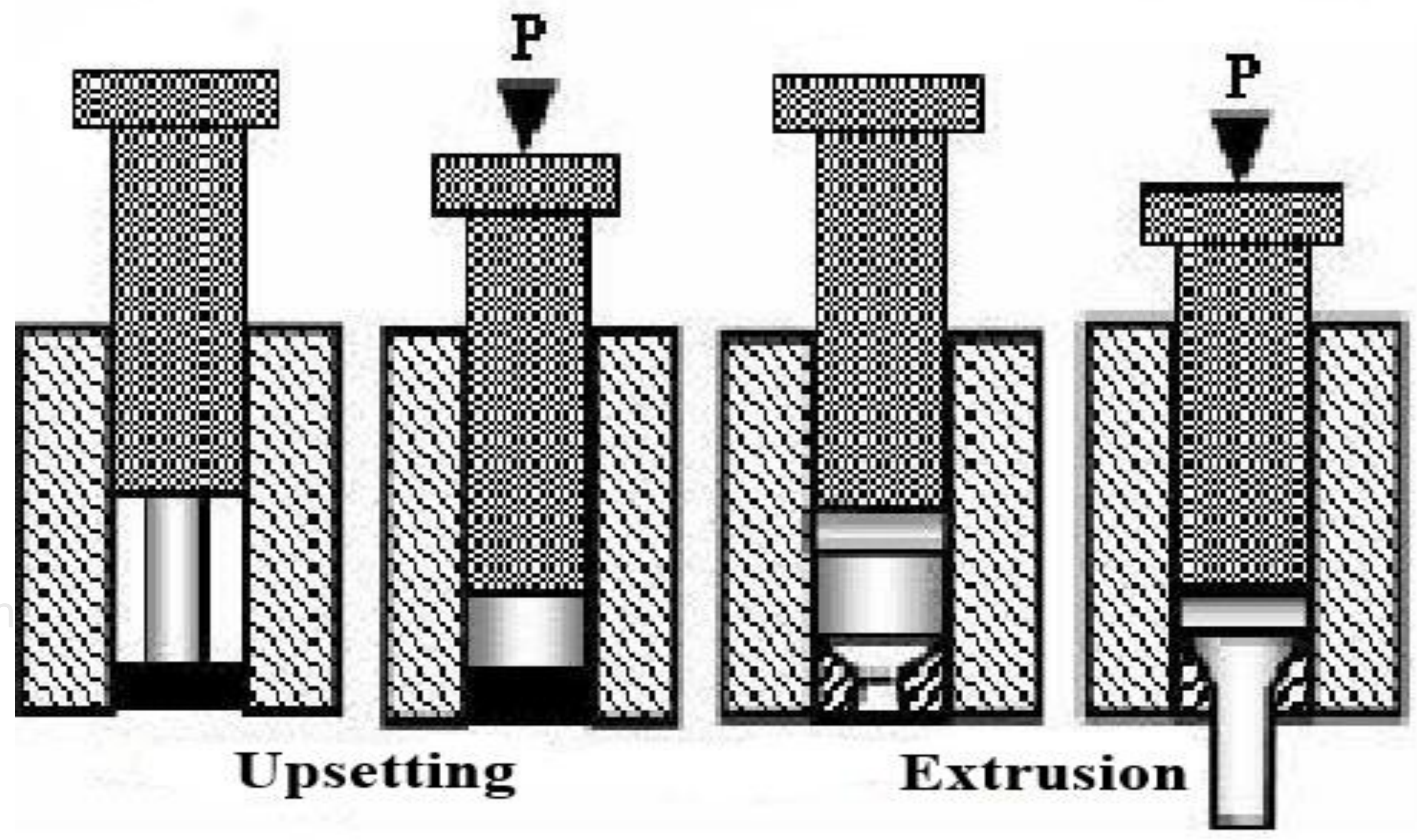
Abstract

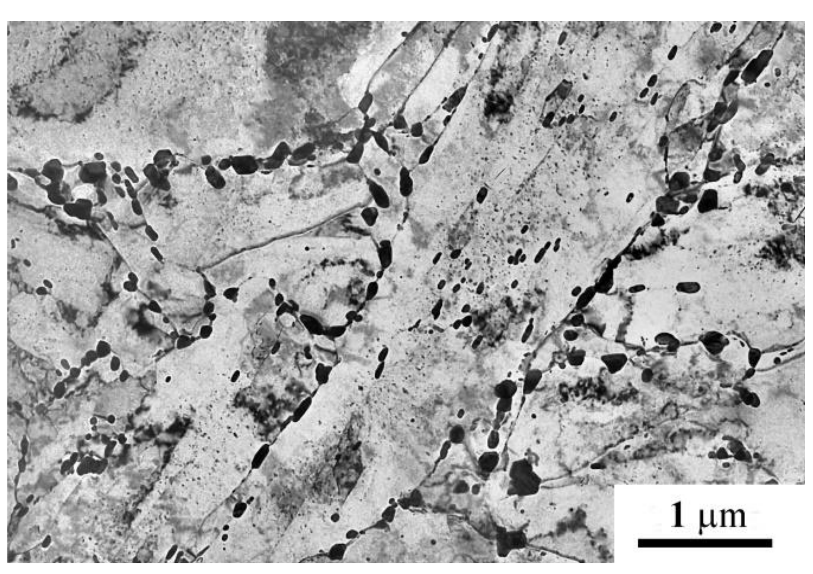
- Ferritic-martensitic (F/M) steels are considered as promising materials for future new generation nuclear reactors. The determining parameters for its successful use in this field are the high radiation resistance and high mechanical characteristics (yield stress, long-term strength etc.) at temperatures above 500 °C. These characteristics are structurally sensitive and can be significantly improved by grains’ refining and creating a large number of nanosized precipitates of carbide phases in the steel.
- In this study, we investigated the possibility of controlling of the density and size of precipitates in F/M steel T91 by severe plastic deformation (SPD) and subsequent heat treatment in various modes.
- The multiple “upsetting-extrusion” (MUE) method was chosen for carry out the severe plastic deformation, which was developed in NSC KIPT.

Schematic diagram of one cycle of “upsetting-extrusion”

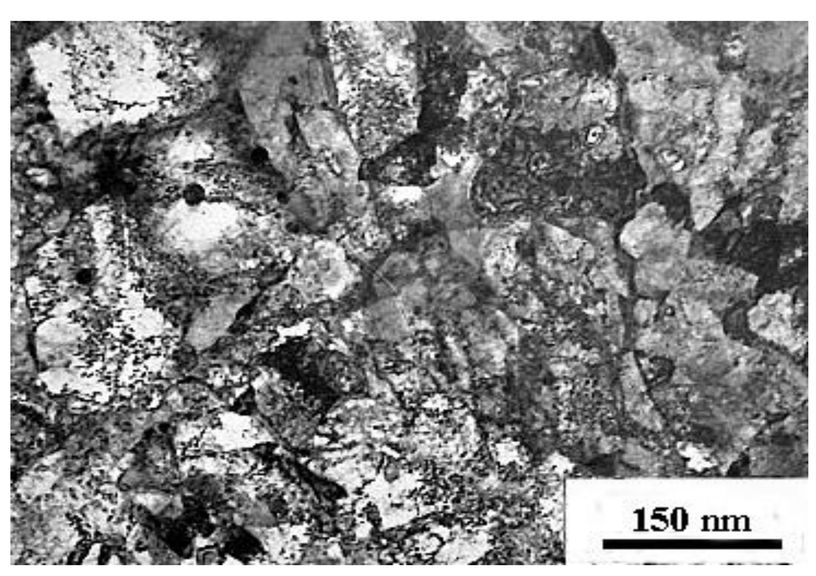


This method proved to be effective for production of ultrafine-grained materials in laboratory and industrial conditions (the diameter of billets varied from 20 mm to 250 mm). Earlier this method was successfully used for production of ultrafine-grained beryllium, tantalum, titanium, zirconium, niobium-titanium and zirconium-niobium alloys. The use of this method allowed to accumulate the required degree of plastic deformation while saving the dimensions of samples.

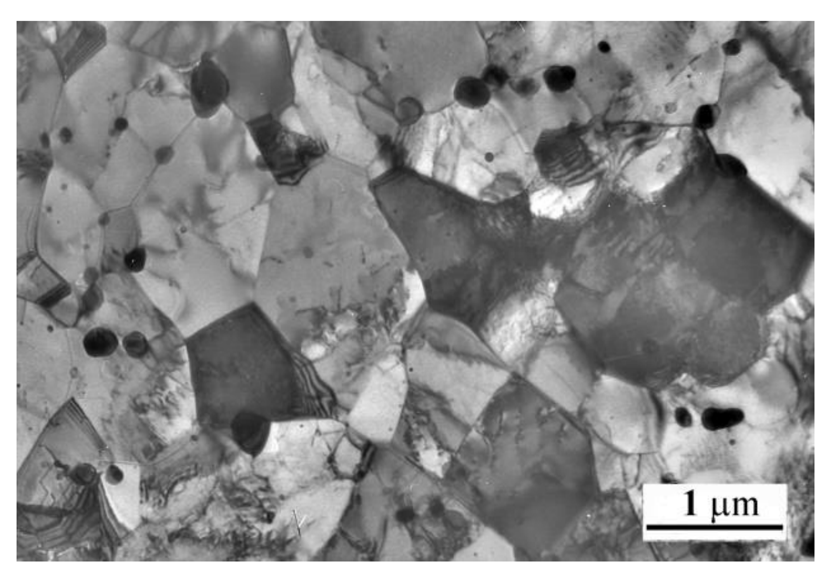
Structure of samples: as-received and after severe plastic deformation (SPD)



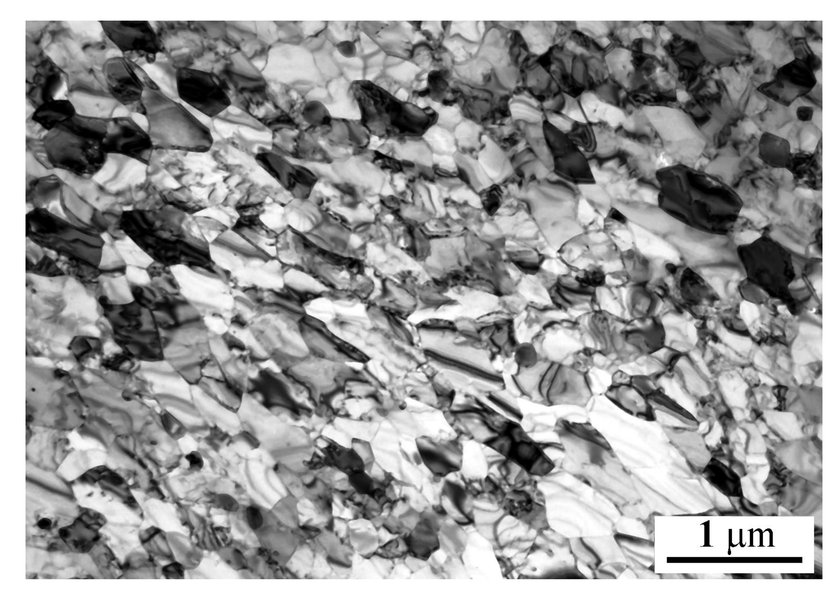
As-received state



After extrusion at 875°C



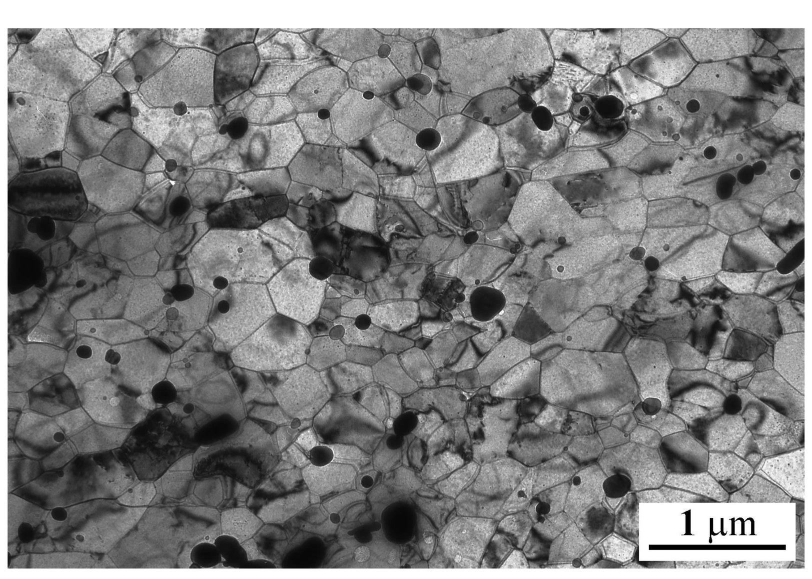
3 cycles of “upsetting-extrusion”



5 cycles of “upsetting-extrusion”

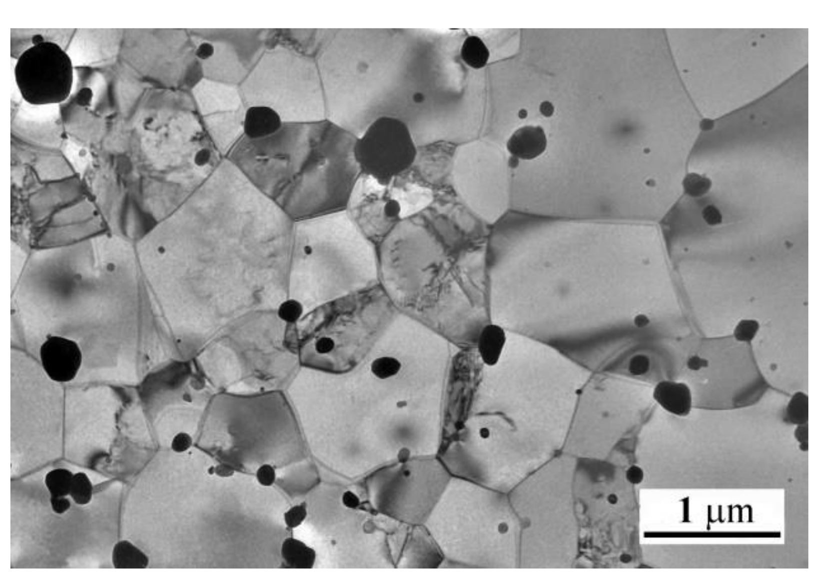
Cylinder specimens with diameter and height of 40 mm were produced from the initial billet. The extrusion of specimen at T = 875°C from diameter 40 mm to 20 mm was carried out. Obtained specimens with diameter 20 mm an height 60 mm were subjected to severe plastic deformation by the multiple “upsetting-extrusion” (MUE); such method means multiple operations of upsetting and extrusion on hydraulic press DB 2432A with force of 160 tf . Real (**logarithmic**) deformation during one cycle of “upsetting-extrusion” was e ~1.6. Five cycles were carried out in ferrite range on successive decrease of deformation temperature from 750°C during first cycle to 575°C during the last one. **The whole temperature cycle of deformation: 750-700-650-635-575°C**

Structure of SPD samples after thermal treatment



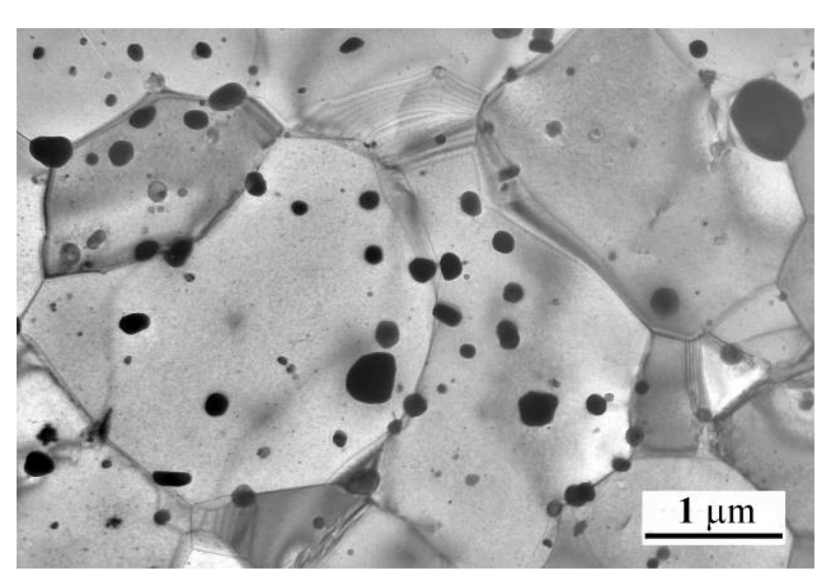
5 MUE + 550°C, 25 h

Type	d_p, nm	ρ, 1/m³
$M_{23}C_6$	133	3.6×10^{19}
MX	11	1.97×10^{21}



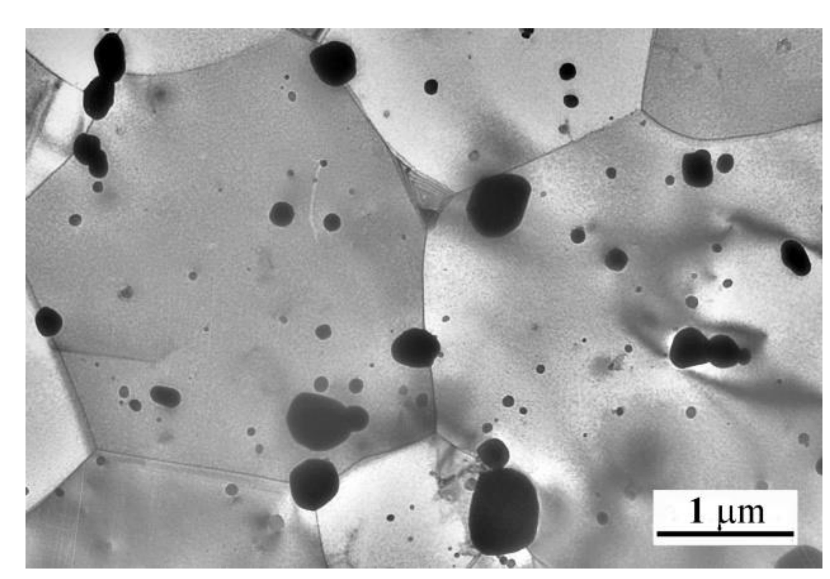
5 MUE + 600°C, 25 h

Type	d_p, nm	ρ, 1/m³
$M_{23}C_6$	140	3.0×10^{19}
MX	16	5.9×10^{20}



5 MUE + 650°C, 25 h

Type	d_p, nm	ρ, 1/m³
$M_{23}C_6$	147	4.2×10^{19}
MX	11	1.2×10^{20}



5 MUE + 740°C, 1 h

Type	d_p, nm	ρ, 1/m³
$M_{23}C_6$	154	3.5×10^{19}
MX	15	1.0×10^{21}

Conclusions

❖**$M_{23}C_6$ precipitates density in SPD samples are practically independent on thermal treatment temperature and their mean size increases a few with the temperature increase.**

❖ **Density of MX precipitates is maximal (1.97×10^{21} 1/m³) and size of precipitates is minimal (11 nm) after thermal treatment at 550°C during 25 hours. The achieved value of the density of nanosized MC precipitates is significantly higher than in the initial state (6.5×10^{19} 1/m³), and their size is almost two times smaller. Thus, the proposed thermomechanical treatment made it possible to significantly modify the microstructure of the promising T91 reactor steel.**