MICROSTRUCTURE AND MECHANICAL PROPERTIES OF MAR-M-247 NICKEL SUPERALLOY

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Abstract

MAR-M-247 is a nickel-base superalloy developed for applications requiring high strength at elevated temperatures up to about 1000 ºC. Its balanced composition provides an excellent combination of tensile and creep-rupture properties as a result of gamma-prime strengthening enhanced by solid solution and grain-boundary strengthening. MAR-M-247 has good castability. It is usually used for turbine blades and turbocharger wheels castings. Heat treatment is usually applied.

Different shape and weight of castings implies different conditions during solidifying and cooling resulting in different castings microstructure. When approving the castings, mechanical values are measured by tensile test on test bodies made from castings with different microstructure. This work investigates correlations between mechanical properties and microstructure, particularly grain size and texture, carbides, casting defects, and gamma-prime phase.

Keywords: Superalloys, microstructure, mechanical properties, carbides

1. INTRODUCTION

MAR-M-247 is a nickel-base superalloy developed for applications requiring high strength at elevated temperatures up to about 1000 ºC. Its balanced composition provides an excellent combination of tensile and creep-rupture properties as a result of gamma-prime strengthening enhanced by solid solution and grain-boundary strengthening. MAR-M-247 has good castability. It is usually used for turbine blades and turbocharger wheels castings. Heat treatment is usually applied.

Recently, customers demand the production of increasingly larger parts of impellers than before. This requirement has resulted in a greater weight of castings and thus different conditions during solidifying and cooling of the castings. Therefore, modified castings microstructure arises.

When approving the castings, mechanical values are measured by tensile test on test bodies made from castings with different microstructure. This work investigates correlations between mechanical properties and microstructure, particularly grain size and texture, carbides, casting defects, and gamma-prime phase.

2. EXPERIMENTAL

The chemical composition of the MAR-M-247 alloy melt used is given in **Table 1**.

Table 1 Chemical composition (in wt. %) of the MAR-M-247 alloy

C	Cr	Mo	Al	Ti	W	Co	Ta	Zr	B	Hf
0.14 - 0.16	8.2 - 8.6	0.6 - 0.8	5.4 - 5.6	0.8 - 1.2	9.8 - 10.3	9.7 - 10.3	2.9 - 3.1	0.03 - 0.06	max. 0.02	1.2 - 1.6

Castings were vacuum investment cast in PBS Velká Bíteš foundry. Three types of castings were examined. First one from the centre of heavy “quatrefoil” casting, second one conical sample, and the third one from casting with 6 mm in diameter. Experimental work consisted of tensile test at room temperature and consequent metallographic (light metallography - LM) and fractographic analysis (scanning electron microscopy - SEM). Grain size, gamma prime phase size, amount of casting defects and carbides were determined. EBSD analysis was performed to evaluate grain orientation and deformation localisation by means of kernel average misfit (KAM).

3. RESULTS

Experimental results of three different castings are given in **Table 2**. Interesting and important structural features are documented on following figures, see **Figures 2-6**.

Table 2 Mechanical properties and microstructure parameters of different castings of the MAR-M-247 alloy

Casting	***Rp*0.2** (MPa)	***Rm*** (MPa)	***A*** (%)	**Grain size** (mm)	**Void fraction on section** (%)	**Void fraction on fracture** (%)	***Dv* - γ' mean size** (μm)
light	838	1202	11	0.298	0.004	0	0.537
medium	844	975	4.1	0.652	0.056	0.082	0.368
heavy	777	867	3.75	0.714	0.012	0.038	0.596

Heavy castings exhibit rather low mechanical properties, especially elongation. Linear correlation between stress and deformation, hence rupture strength and elongation, is found in region of homogenous plastic deformation in stress-strain diagram. Light castings performed, approx. two times, higher strain hardening rate than other castings, see **Figure 1**.

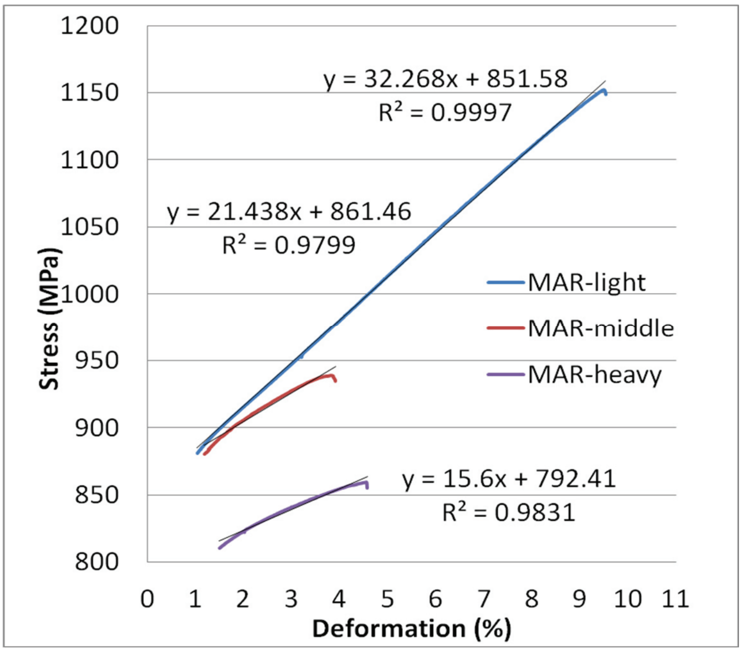


Figure 1 Strain hardening of different MAR-M-247 castings

Important differences are found in grain size, see **Figure 2**. Investigation of metallographic sections and fractures shows very low void fraction, but large amount of carbides, see **Figures 3 and 4**. Intergranular cracks are found, which were caused by long needle-like particles (2 - 3 μm thin, 50 - 100 μm long) in case of heavy castings. Most of the fracture surface of light casting is covered by marks of ductile fracture, see **Figure 4**. γ' phase particles size and distribution is a result of heat treatment, see **Figure 5**.

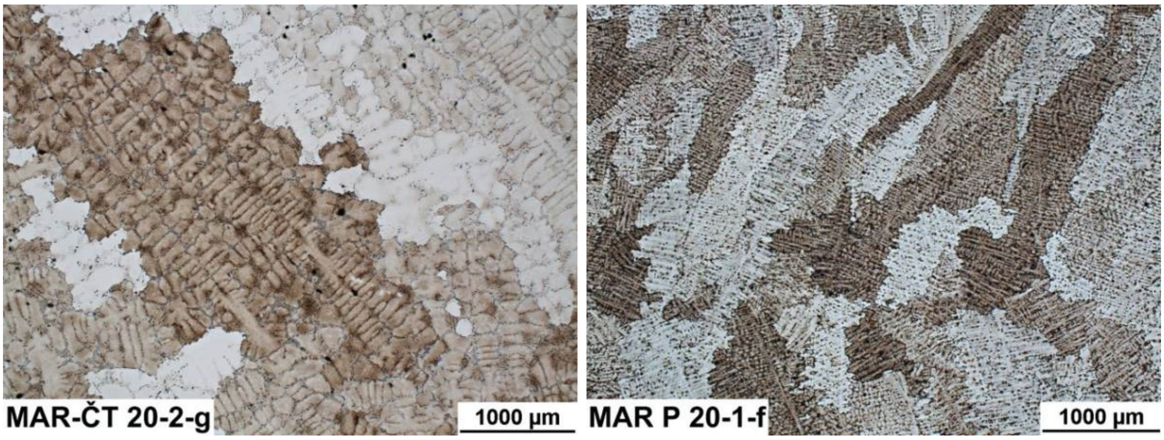


Figure 2 Macroetched longitudinal metallographic section of tensile test specimen from heavy (left) and light casting (right) - LM

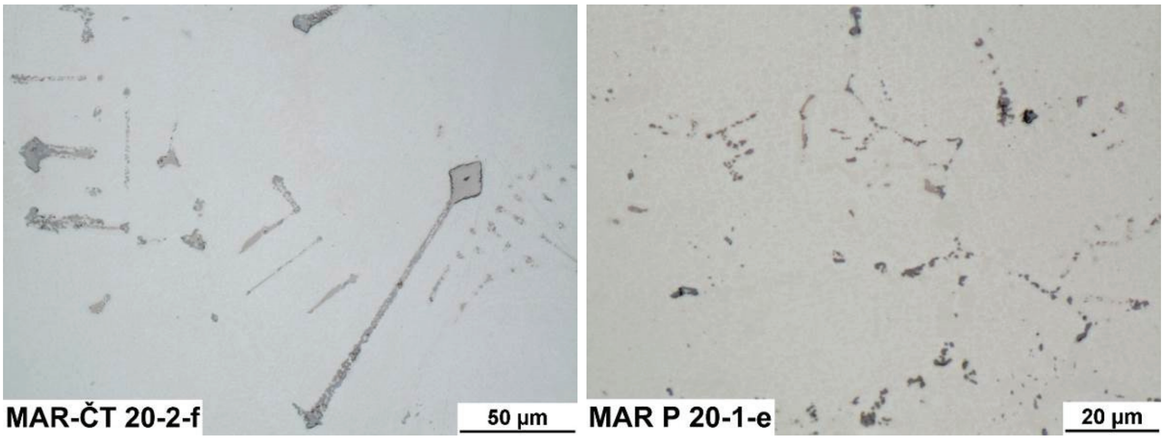


Figure 3 Non-etched longitudinal metallographic section of tensile test specimen from heavy (left) and light casting (right) with different carbides size and morphology - LM

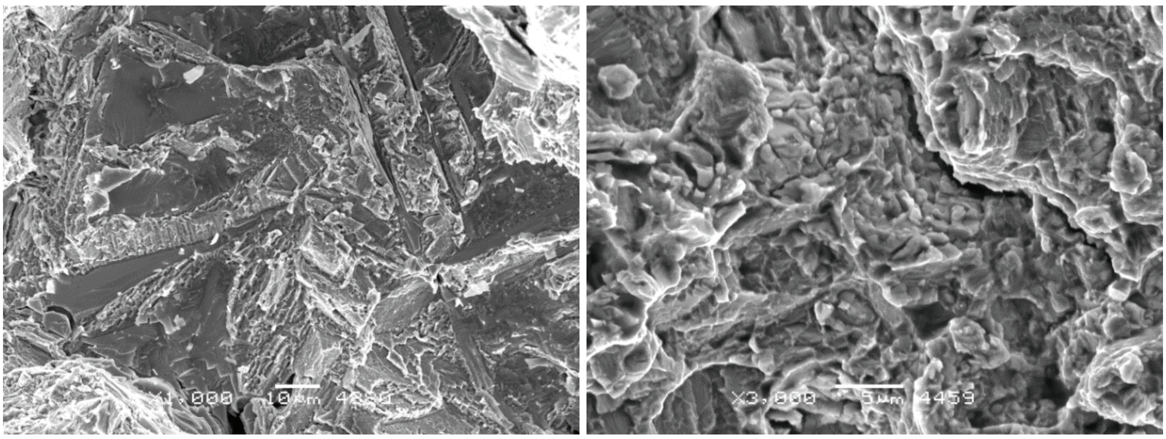


Figure 4 Broken carbides on fracture surface from heavy casting (left), fracture surface with ductile dimples from light casting (right) SEM

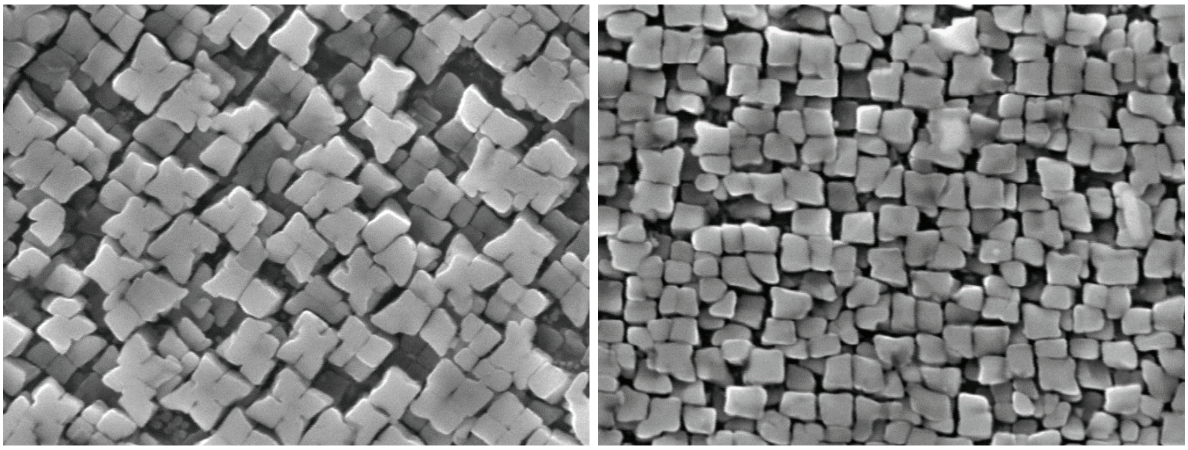
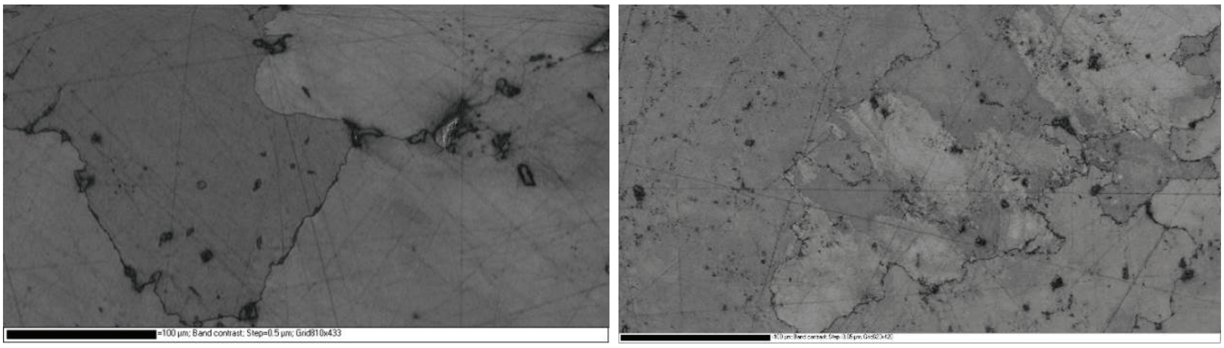
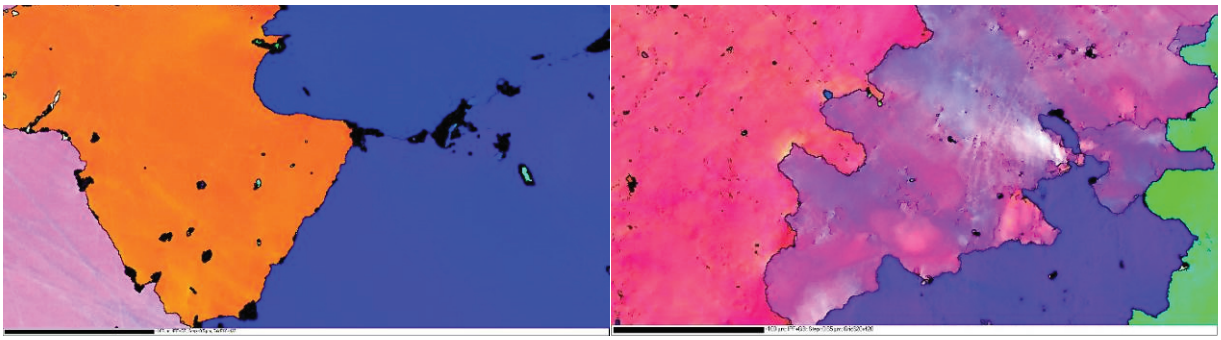


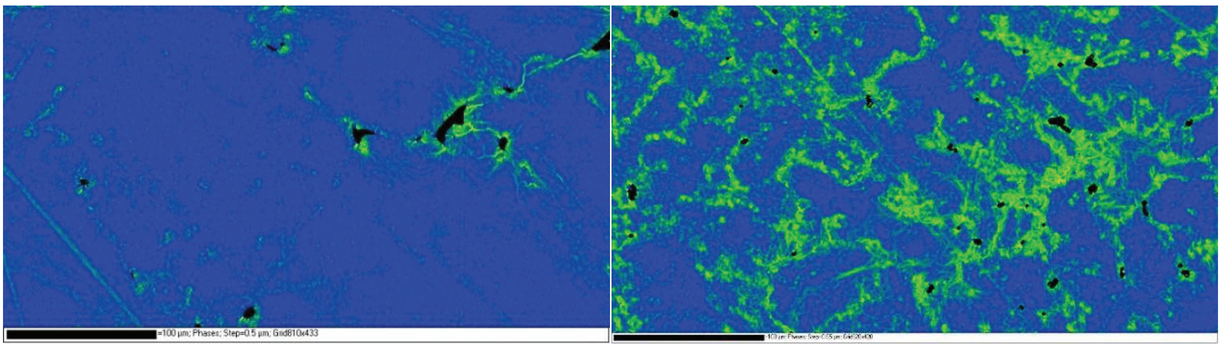
Figure 5 Gamma prime phase particles morphology from heavy (left) and light casting (right) - SEM



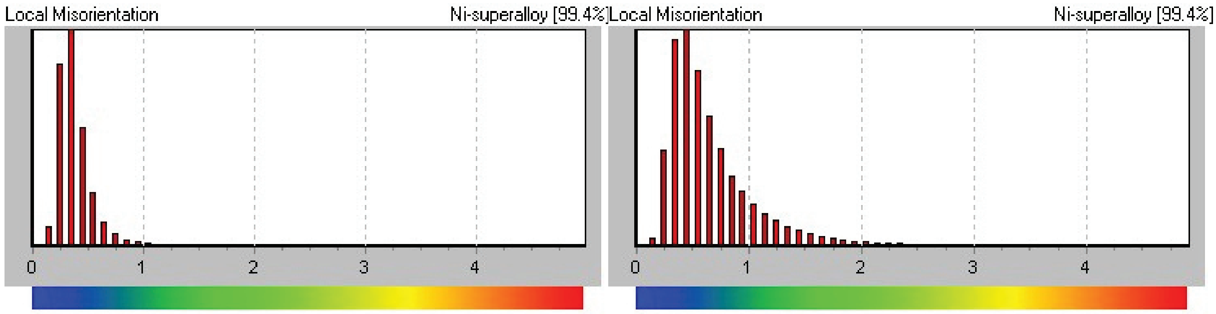
a)



b)



c)



d)

Figure 6 a) band contrast, b) inverse pole figure c) kernel average orientation misfit map of selected places of heavy (left) and light casting (right). d) Histograms of local misorientation and legend to KAM map of heavy (left) and light casting (right)

Local maxima of local misorientation are found at grain boundaries and interdendritic regions. Larger maxima can be found in microstructure of light castings, see **Figure 6**.

4. DISCUSSION

Presented results showing reduction of mechanical properties of MAR-M-247 alloy are similar to published results of MAR-M-247 alloy, e.g. [1, 2], or of IN713LC alloy [5] in literature. Both publications connect carbides with low elongation values. Milenkovic [2] connected directly cooling rate with carbides fraction and carbide size.

Local misorientation can be related to local excess dislocation density [3], [4]. Usually places with high local grain misorientation are located near carbides. Higher dislocation densities near the carbides are reported [4] to be generated by the large strain gradients produced around the plastically rigid inclusion during mechanical deformation.

Strain hardening is connected with obstacles for dislocation movement. Some researchers [6] correlated γ' particles size with strain hardening, which is not probably our case. In our case, it can be result of smaller grain size and dendrite arm spacing resulting from higher cooling speed during solidification. Grains and interdendritic regions are also obstacles for dislocation, especially when decorated by carbides. Higher KAM values might be also a result of higher overall elongation due to precipitation of discontinuous carbide particle, which is also result of higher cooling speed.

Further investigation is needed to gain closer insight in observed differences in strain hardening of MAR-M-247 cast nickel superalloy.

5. CONCLUSION

MAR-M-247 nickel superalloy castings with different weight were investigated. It was shown, that room temperature tensile properties are directly influenced by castings microstructure and thus solidifying and cooling conditions. Most important microstructure features are presence of long needle-like carbides and gamma prime phase mean particle size. Strain hardening is connected with grain size, carbides and dendrite arm spacing.

ACKNOWLEDGEMENTS

This research was sponsored by the Czech Ministry of Industry and Trade, programme TIP, project FR-TI4/030.

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