The influence of alloying elements on the microstructure and selected high-temperature options - new positions of superalloys on the cobalt matrix reinforced with the L12 phase.

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Introduction

The study investigated the primary structure of the new generation of superalloys based on Co-10Al-5Mo-2Nb and Co-20Ni-10Al-5Mo-2Nb type cobalt. Research on a group of cobalt-based materials was initiated in 2006 by J. Sato. These materials may replace nickel based superalloys in the future due to their excellent properties at elevated temperatures relative to nickel based superalloys. Primary microstructure characterization of Co-10Al-5Mo-2Nb and Co-20Ni-10Al-5Mo-2Nb alloy are the basic subject of this article. Co-10Al-5Mo-2Nb and Co-20Ni-10Al-5Mo-2Nb alloy are a tungsten free alloy of new type with final microstructure based on Co based solid solution $L1_2$ phase of $Co_3(Al,Mo,Nb)$ type as a strengthened structural element. The analyzed alloys were investigated in as-cast state after vacuum casting process to the graphite molds. The primary microstructure of alloy were analyzed by light, scanning electron microscopy and transmission microscopy as well as the chemical constituent of dendritic and interdendritic areas. Currently, nickel-strengthened γ 'phase steels are still unrivaled in aerospace applications, however, cobalt based superalloys are a response to their existing limitations, which do not allow maintaining the current rate of development of aircraft engines

Materials

The research material consisted of Co10Al5Mo2Nb and Co20Ni10Al5Mo2Nb alloys. They were the product of the casting process in the form of a bar with a size of 20 × 100 mm (the shape of the castings is shown in Figures 1 and 2). The chemical composition of the cast alloys is shown in Tables 1 and 2.

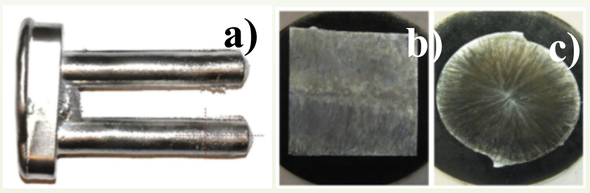


Fig. 1.a) view of the Co-10Al-5Mo-2N superalloy casting, b) longitudinal section and c) cross section through the bar

Element	Al	Mo	Nb	Co
at%	8,5	4,6	2,0	reszta
wt%	3,9	7,6	3,2	reszta

Tab. 1. The actual chemical composition of Co-10Al-5Mo-2Nb superalloy

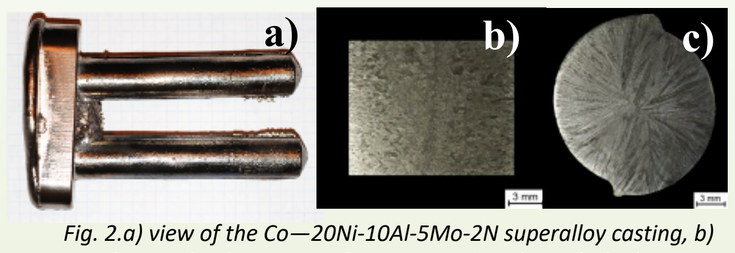


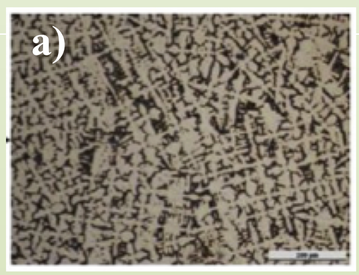
Fig. 2.a) view of the Co—20Ni-10Al-5Mo-2N superalloy casting, b) longitudinal section and c) cross section through the bar

Element	Ni	Al	Mo	Nb	Co
at. %	20.5	9.8	5.2	2.4	reszta
wt. %	20.6	4.5	8.5	3.8	reszta

Tab. 2. The actual chemical composition of Co-20Ni-10Al-5Mo-2Nb superalloy

Results

After casting, the Co10Al5Mo2Nb alloy is characterized by a microstructure of a solid cobalt solution (austenitic) with a low proportion of primary precipitates in the interdendritic regions. The microstructure of the alloy as observed using a light microscope (LM) is shown in Figure 3a). Fig. 3b) shows the microstructure observed on the scanning electron microscope (SEM) and the analysis of the separation area. In the alloy structure there are precipitates of complex shape containing a greater amount of niobium and molybdenum relative to the matrix. X-ray studies of the phase composition have shown that these precipitates may consist of Co3Mo and Co3Nb phases (Fig. 4).



Element¤	Wt%¤	At%¤
Al¤	03.3¤	07.6¤
Nb¤	17.6¤	11.9¤
Mo¤	10.5¤	06.9¤
Co¤	68.7¤	73.6¤

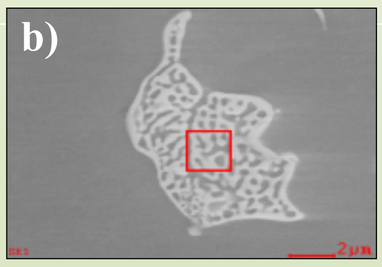


Fig. 3. Microstructure of the Co-10Al-5Mo-2Nb superalloy a) equiaxial crystals (LM) b) Results of X-ray microanalysis for selected areas of the alloy structure (SEM)

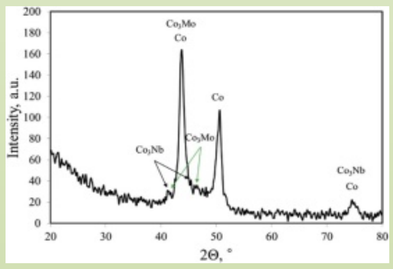
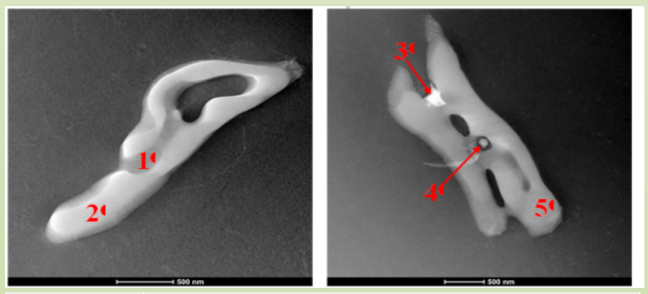


Fig. 4. X-ray diffraction pattern of the Co-10Al-5Mo-2Nb superalloy in the cast state



Pierwiastek	Wt [%]				
	1	2	3	4	5
Al	1,4	0,8	-	3,0	1,5
Co	67,4	58,3	3,8	29,1	59,9
Nb	21,8	28,4	92,3	66,1	27,0
Mo	9,5	12,5	3,9	1,8	11,7

Fig. 6. Images of the Co-10Al-5Mo-2Nb superalloy microstructure observed in TEM with the use of the HAADF detector. The table presents the results of EDX microanalysis for selected measuring points

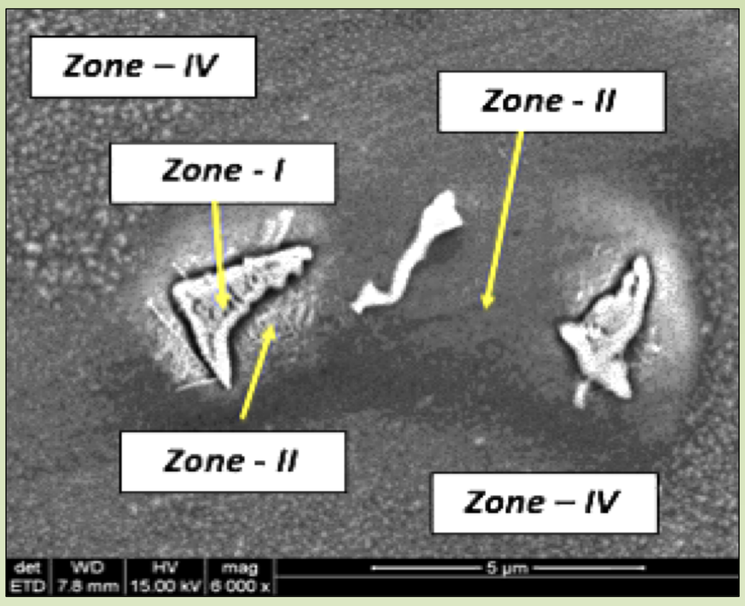


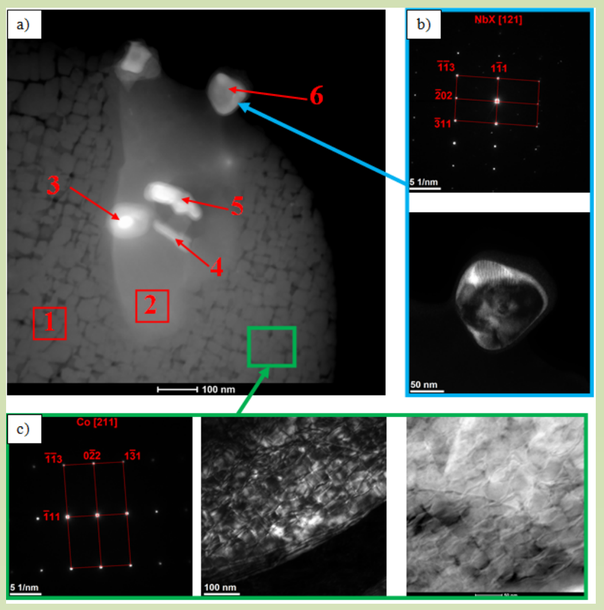
Fig. 7. Detailed localization of structural zone from I to IV in Co-20Ni-10Al-5Mo-2Nb alloy in as-cast condition (SEM).

First of them consists precipitation in the morphology typical for eutectics (Figs 3 a,b). In direct surroundings of this structural element, it can be defined another one element with other chemical composition and needle-like morphology. The morphology of observed elements suggests the presence of eutectic of $Co/Co_3(Al,Mo,Nb)$ (first zone) type with nodular precipitation of Co_3Mo and/or Co3Nb phase with D019 type of lattice (second zone). The third visible structurally other areas is sheath of this two sub-zones without presences of eutectic form but with very ultrafine-grained precipitations of probably primary $L1_2$ phase with formula $Co_3(Al,Mo,Nb)$.

The last identified morphological form is Co based solid solution as a matrix with fine-grained precipitation of probably primary $L1_2$ phase with formula $Co_3(Al,Mo,Nb)$. In comparison earlier mentioned ultrafine-grained precipitations, in this zone this structural element is much higher in size, and shape similar to spheroidal or cuboidal.
As mentioned earlier the morphology of this precipitation conforms these suggestions. Interesting observations were made in zone IV, where practically pure Co-based solid solution was identified with small addition of ultrafine precipitations (suggestion of ultrafine grained $Co_3(Al,Mo,Nb)$ phase presences). This microstructural effect suggests also the impoverishment to alloying elements such as Mo and Nb (in contrary to chemical composition analysis in this zone presented in Table 3. The studies carried out with the use of transmission microscopy also showed that the alloy matrix is made of the RSC solid cobalt solution, which was confirmed by selective electron diffraction (Fig. 8). Regions rich in niobium were also observed, favoring the release of Co3 (Al, Mo, Nb) phases and NbX-type precipitates

Tab. 3. Measured chemical composition of analyzed Co-20Ni-10Al-5Mo-2Nb alloy.

Zone		Co	Ni	Al	Mo	Nb
I	at. %	57.89	13.87	4.95	6.82	16.58
II		59.20 ↑	19.27 ↑	8.67 ↑	5.65 ↓	7.22 ↓
III		59.23 ↑	20.20 ↑	9.02 ↑	5.97 ↓	5.58 ↓
IV		62.72 ↑	21.31 ↑	9.52 ↑	4.88 ↓	1.58 ↓
I	wt. %	52.01	12.43	2.04	9.99	23.53
II		57.51 ↑	18.65 ↑	3.86 ↑	8.94 ↓	11.05 ↓
III		58.07 ↑	19.73 ↑	4.05 ↑	9.53 ↓	8.62 ↓
IV		63.53 ↑	21.50 ↑	4.42 ↑	8.04 ↓	2.52 ↓



Pierwiastek	Wt [%]					
	1	2	3	4	5	6
Al	3,7	5,2	0,4	1,1	1,7	-
Co	58,3	40,4	39,7	35,4	22,6	0,6
Ni	19,2	7,4	7,8	12,8	10,2	0,1
Nb	5,4	31,4	42,0	45,5	62,9	99,1
Mo	13,4	15,6	10,1	5,2	2,6	0,2

Fig. 8. Images of the microstructure of the Co-20Ni-10Al-5Mo-2Nb superalloy observed in S / TEM: a) matrix fragment with precipitates, b) diffraction and dark field from the marked precipitation, c) diffraction, dark field and HAADF image from the matrix What. The table presents the results of EDX microanalysis for selected measurement points.

Conclusions

The dendrite core regions that are rich in Mo and Nb (in solid solution) showed a much stronger tendency to form the primary phase of $Co_3(Al, Mo, Nb)$ in a spherical/cuboidal form. The structure also identified exclusions of the MX type, based predominantly on niobium.