STRUCTURE AND MECHANICAL PROPERTIES OF TYPE 718 ALLOY WITH INCREASED CONTENT OF REFRACTORY ELEMENTS

V.B.Kireev and O.V.Makushok
I.P.Bardin Central Research Institute
for Iron and Steel Industry

Moscow, USSR

ABSTRACT

718 alloy type nickel-base superalloys have found wide application in many engineering fields owing to their high levels of strength and ductility. This study deals with the effect of refractory elements (W, Mo) on the structure and mechanical properties of a weldable Ni-base superalloy with 5.3-6.5 wt.% Nb. It is shown that additions of 6-8 wt% W and 3.5-5 wt.% Mo, with Fe level up to 5 wt.%, increase the alloy working temperature up to 800 C.

Analyses of phase composition and mechanical properties of the alloy after prolonged high-temperature ageing to high structural stability in the range 700-800^{O}C. Heat treatment conditions are suggested, capable of ensuring the required of creep strength and mechanical properties. Structural and property studies of cast and wrought alloy confirm its suitability for the manufacture of formed-welded and cast components of intricate geometry.

Superalloys 718, 625 and Various Derivatives
Edited by Edward A. Loria
The Minerals, Metals & Materials Society, 1991

Nickel superalloys (type 718 alloy) with 4.5-5.5 wt.% Nb have found wide application for formed-welded and cast parts operating at temperatures up to 700°C. The success of these alloys in mechanical engineering should be ascribed to their high level of physical and mechanical properties, resistance to oxidation and high-temperature salt corrosion, and good workability.

This study deals with the structure and mechanical properties of a Soviet make nickel-base alloy (EP902) [1] which differs from 718 alloy on account of higher levels of tungsten, molybdenum, aluminium and niobium, absence of titanium and limited iron content (Table I).

Table I. Composition of commercial EP902 alloy (wt.%)

C	Cr	W	Mo	Nb	Al	Fe	Ce	Zr	Ni
≤0.1	14-16	6.1-7.5	3.5-5.0	5.3-6.5	.5-1.8	≤5.0	≤0.02	≤.025	bal

The following principles governed the design of this alloy:

(a) Higher levels of refractory alloying elements (W, Mo) favour γ-solid solution hardening, reduce diffusion mobility of atoms and retard coalescence of the strengthening phase particles.

(b) Restriction of iron content combined with higher levels of molybdenum and tungsten inhibit the formation of topologically close-packed μ-phase which is known to impair high-temperature strength and ductility.

(c) Increasing aluminium and decreasing iron content retards the transformation of $Ni_3(Nb,Al)$ γ'-phase into Ni_3Nb laminated δ-phase.

Such an approach yielded an alloy strengthened with $Ni_3(Nb,Al)$ phase suitable for prolonged service at temperatures up to 750-800°C in both cast and wrought state.

The structure and mechanical properties of this alloy after plastic deformation were studied on specimens of rolled bar produced from an ingot melted in an open induction furnace.

Table II . Mechanical properties of strained EP902 alloy after two-stage heat treatment

Properties		Test temperature (^{o}C)			
		20	600	700	750
σ_B	MPa	1170	970	850	720
$\sigma_{0.2}$	MPa	800	750	750	670
δ_5	%	30	20	15	14
KCV	MJ/ m^2	1.5	1.5	1.5	1.5

After heat treatment (1100^{o}C - air cooling + 750^{o}C - - 15 h - air cooling) the structure is characterized by a fine grain (60 μm) with thin boundaries and uniformly distributed dispersed γ'-phase (Fig. 1), and ensures a combination of improved strength and ductility throughout the range of working temperatures (Table II).

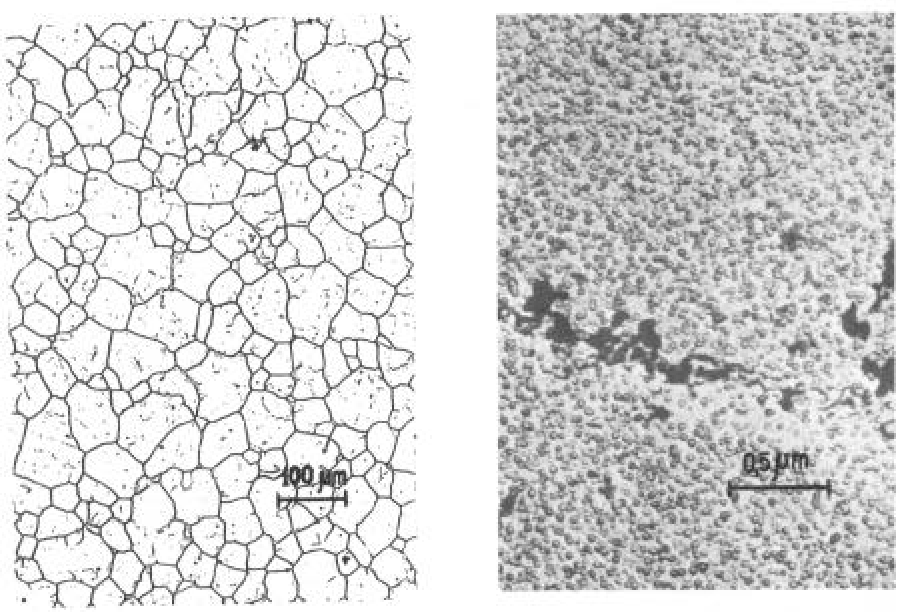


Fig. 1. Microstructure of wrought EP902 alloy

Additional low-temperature ageing at 650°C for 15 h (air cooling) promotes the increase of strength in the temperature range 20 to 600°C, with somewhat lower levels of ductility (Table III).

Table III. Mechanical properties of wrought EP902 alloy after three-stage heat treatment

Properties		Test temperature (°C)			
		20	600	700	750
σ_B	MPa	1350	1070	840	680
$\sigma_{0.2}$	MPa	930	820	720	580
δ_5	%	30	8.5	6.5	6.0
KCV	MJ/ m^2	1.0	1.0	1.0	1.0

Prolonged ageing of the alloy at 700°C does not essentially affect on the mechanical properties (20°C), an indication of high structural and phase stability during service (Table IV).

Table IV. Mechanical properties of wrought EP902 alloy at 20°C after prolonged ageing at 700°C

Ageing time (h)	σ_B (MPa)	$\sigma_{0.2}$ (MPa)	δ_5 (%)	KCV (MJ/ m^2)
0	1350	930	30	1.3
500	1350	920	30	1.1
1000	1350	920	30	1.1

The results of creep-rupture strength tests at 600-800°C are presented in Table V.

EP902 alloy features high heat resistance: the rate of oxidation in air at 1100°C is ~0.5 g/m^2h over 1000 h period.

The structure and mechanical properties of the as-cast alloy were studied on specimens cast in ceramic moulds. Retarded cooling of the alloy with the mould reveals dendrite inhomogeneity. Segregation of the refractory elements into the interdendritic zones yields type MC/Nb(C,N) and M_6C carbides and flakes of rhombic-lattice Ni_3Nb δ-phase (Fig. 2a). The total amount of these phases is ~0.8%, some 0.5% being the share of Nb(C,N) carbonitrides. On cooling of the cast alloy the strengthening $Ni_3(Nb,Al)$ fcc

Table. V. Creep-rupture strength of wrought EP902 alloy

Test temperature (°C)	Stress (MPa)	Time to fracture (h)	δ_5 (%)
600	600	7151	2.5
650	550	1078	2.8
700	450	446	7.2
700	400	760	12.8
700	350	2141	10.0
750	250	496	18.8
750	200	1508	19.2
750	150	2775	14.0
800	200	145	33.6
800	150	434	22.4

γ'-phase precipitates in the form of a dispersoid (amount not exceeding ~3%). Increasing solution treatment temperature to 1170°C was found beneficial in reducing the microchemical segregation inhomogeneity and for complete dissolution of the surplus phase (Fig. 2b).

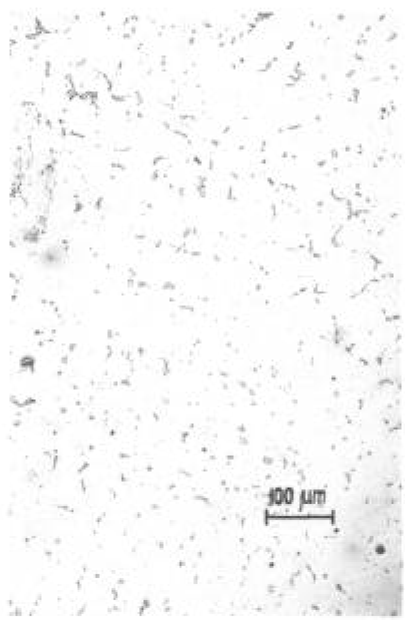
Analysis of the mechanical properties and creep-rupture strength of cast EP902 alloy subjected to various heat treatment modes shows that the best combination of strength and ductility in the range 20 to 800°C is obtained with heat treatment: 1170°C - 3 h

– air cooling + 750°C – 15 h – air cooling (Tables VI and VII).

Table VI. Mechanical properties of cast EP902 alloy after two-stage heat treatment

Properties		Test temperature (°C)			
		20	600	700	750
σ_B	MPa	880	680	720	658
$\sigma_{0.2}$	MPa	750	565	600	598
δ_5	%	12.4	22.6	19.2	12.0
KCV	MJ/mm^2	0.6	0.7	0.6	0.7

a



b

Fig. 2. Microstructure of ЭП902 alloy: as-cast (a) and after solution treatment at 1170°C (b)

Table. VII. Creep-rupture strength of cast EP902 alloy

Test temperature (^{o}C)	Stress (MPa)	Time to fracture (h)	δ_5(%)
600	500	118	4.4
600	400	908	1.2
650	500	2064	12.0
650	500	3014	15.4
700	500	162	5.2
700	420	1558	2.4
700	400	1301	18.4
700	350	2331	16.0
750	350	211	3.6
750	320	489	4.8
800	300	48	5.3
800	280	208	3.0
800	220	614	7.9
800	200	888	16.0
800	150	2000	14.4

Test results relating to creep-rupture strength at 650-700^{o}C of the as-cast alloy are similar to those of wrought bars (Fig. 3), though the time to fracture at 800^{o}C is greater for the as-cast specimens. The cast alloy retains high ductility (δ_5= 12 to 18%) after creep-rupture tests at 650-800^{o}C for 2000-4000 h.

The structure of as-cast alloy in the working temperature range after ageing for 1000 h fails to reveal noticeable changes on ageing at 700^{o}C (Fig. 4a), a similar structure being obtained after creep-rupture tests at 700^{o}C and σ = 350 MPa for 2331 h (Fig. 4b). Ageing at 750^{o}C produces zones enriched with niobium and flakes of Ni_3Nb δ-phase (Fig. 4c). Increasing the ageing temperature to 800^{o}C intensifies the decomposition of the solid solution yielding flakes of δ-phase (Fig. 4d), the γ'-phase retains its morphology and dispersion.

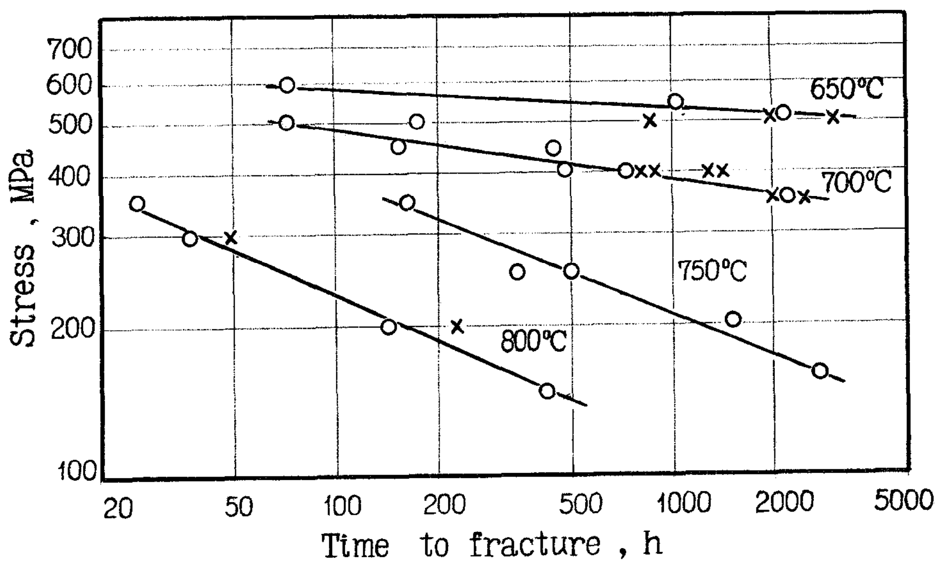


Fig. 3. Time to fracture versus stress for EP902 alloy in wrought state (o) and as-cast (x)

In order to assess the mechanical properties of EP902 alloy after prolonged service, strength and ductility tests were conducted after ageing the alloy for 500 to 5000 h at 700°C (Table VIII).The ductility decreases, but the values are still satisfactory for cast nickel-base alloys after prolonged service at working temperatures. It follows that, essentially, this alloy has little susceptibility to embrittlement and softening in the time-temperature ranged studied, even after ageing for as long as 5000 h.

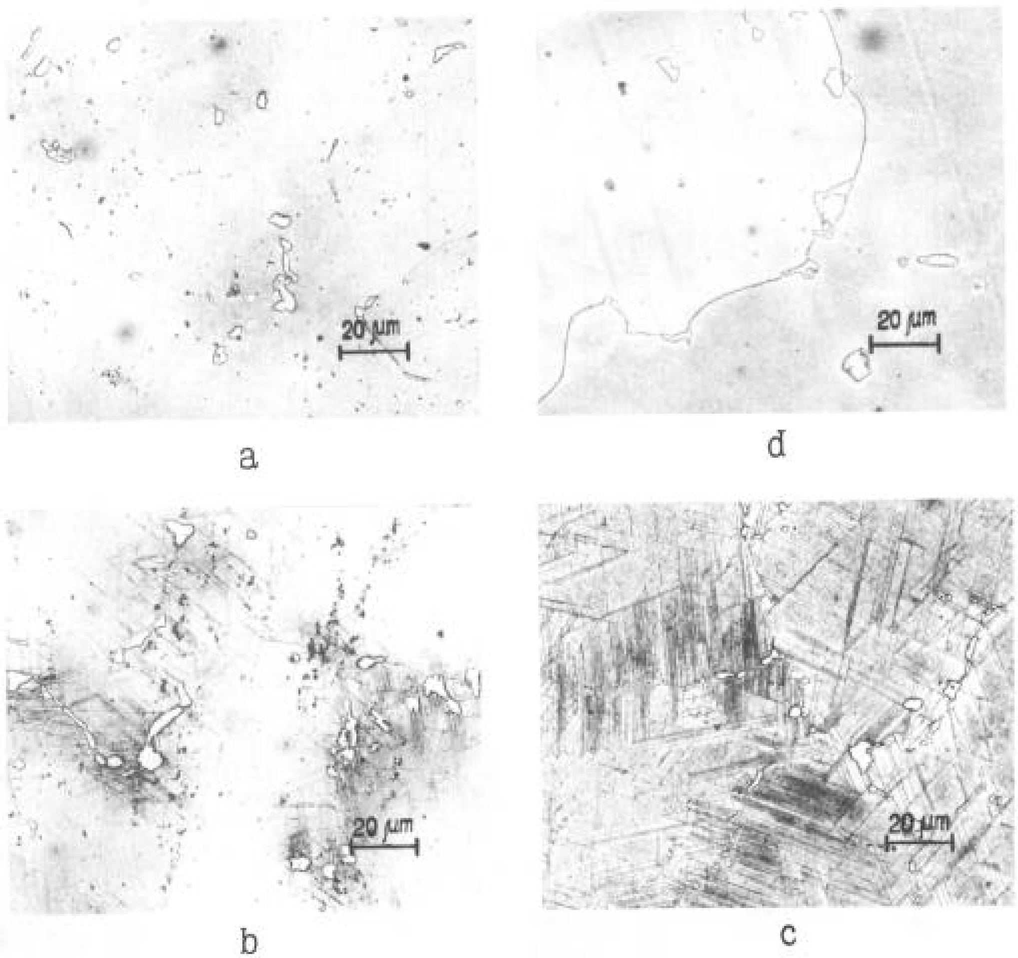


Fig. 4. Microstructure of cast EP902 alloy after ageing for 1000 h at 700°C (a), 750°C (b), 800°C (c) and after creep-rupture tests for 2331 h at 700°C, σ=350 MPa (d)

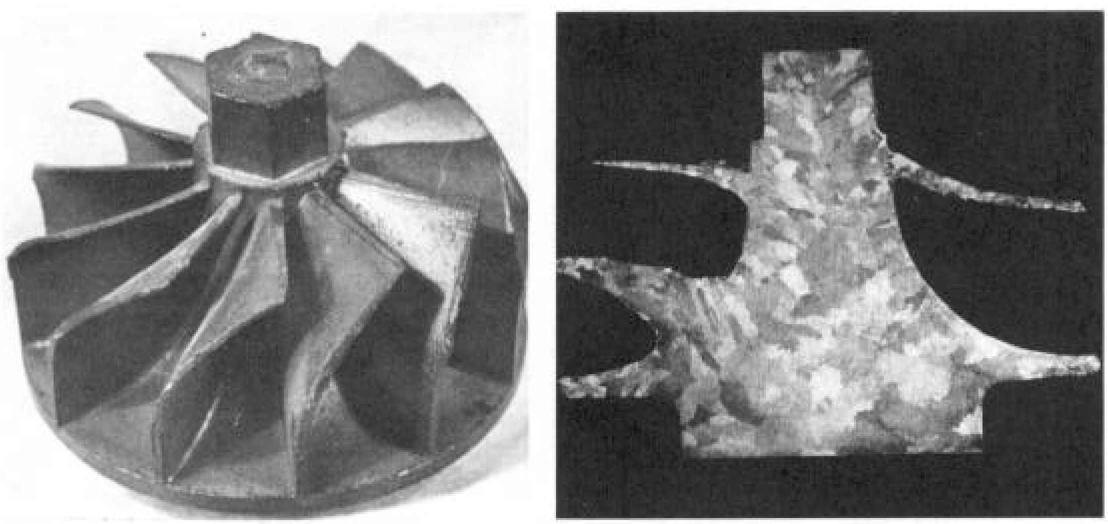
EP902 alloy can be made by induction melting or duplex process involving vacuum arc remelting, depending on end use.

EP902 alloy features a high level of performance characteristics and is used for formed-welded and cast structures. In particular, this alloy is widespread as the material for turbine wheels of superchargers for augmented engines with working temperatures up to 750°C. A general view of a turbine wheel and alloy macrostructure are shown in Fig. 5.

EP902 alloy is available as wrought and cast bar.

Table VIII. Mechanical properties of cast EP902 alloy after prolonged ageing at 700°C

Ageing time (h)	20°C				700°C			
	σ_B (MPa)	$\sigma_{0.2}$ (MPa)	δ (%)	KCV (MJ/mm²)	σ_B (MPa)	$\sigma_{0.2}$ (MPa)	δ (%)	KCV (MJ/mm²
0	880	750	12.4	0.6	720	658	19.2	0.6
500	960	760	12	0.5	670	580	6	0.5
1000	970	760	7	0.4	690	600	6	0.4
3000	970	800	8	0.2	800	670	6	0.2
5000	990	850	6	0.2	800	710	4	0.2



a b

Fig. 5. General view of supercharger turbine wheel (a) made of EP902 alloy and alloy macrostructure (b)

References

1. L.N.Zimina, V.A.Polinets, and V.K.Tsvetkova,"The Use of Heart-Resistant Alloys for Combine Machine Engines",Stal,8 (1982),20-21.