Opportunities and Challenges for the New Nickel Base Alloy 718Plus™

Schreiber, K.[1, a], Loehnert, K.[2, b], Singer, R.F.[2, c]

[1] Rolls Royce Deutschland Ltd. & Co. KG, Eschenweg 11, 15827 Blankenfelde-Mahlow, Germany
[2] Institute of Science and Technology of Metals, University of Erlangen-Nürnberg, Martensstraße 5, 91058 Erlangen, Germany

[a] Karl.Schreiber@Rolls-Royce.com,
[b] Katja.Loehnert@ww.uni-erlangen.de, [c] Robert.Singer@ww.uni-erlangen.de

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Modern jet engines have to meet highest standards in terms of reliability, weight, performance, low emission and service life. Although the degree of technical as well as environmental perfection of civil jet engines is already very high, strong market requirements exist which demand for future jet engines a further cost and weight reduction as well as performance improvements.

In order to realise the future engine architecture, the challenge for materials development is, with respect to high temperature alloys, to make low cost and robust materials available for turbine discs. These materials should be stable up to high temperatures as well as easy to process and weld. Currently used nickel base superalloys like IN718 exhibit low cost, but maximum usage temperature is limited to 600 °C. Alloys with a higher temperature capability than IN718, ranging from 600 to 650 °C, like Waspaloy or Udimet720Li, are more expensive and have inferior processing and welding characteristics. Therefore, a material with the following properties would be required:

- Maximum usage temperature of 650 °C
- Good processability
- Good weldability
- Good LCF properties and low crack propagation rates at high temperatures
- Reasonable cost

In terms of the above listed properties, alloy 718Plus™, which was developed by Allvac, USA, is a promising candidate to be used as a disc material for aero engines. It closes the gap between IN718 and Waspaloy, as it is said to combine the good processability and weldabilty of IN718 with the temperature capability of Waspaloy. The possibility to weld the alloy allows a significant cost reduction in the engine. Fig. 1 illustrates the potential use of wrought alloy 718Plus™ as disc material for high pressure (HP) compressor as well as for high pressure (HP) turbine discs.

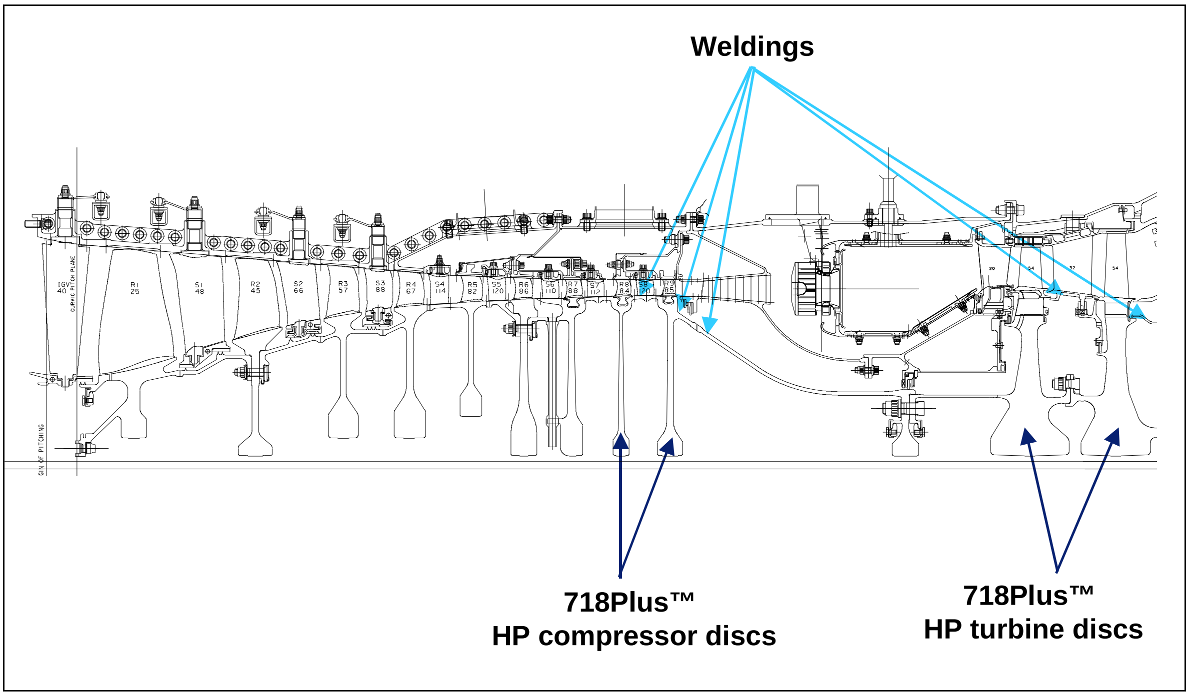

Fig. 1: Potential applications for alloy 718Plus™ in a future high pressure core section

The development of alloy 718Plus™ was carried out in order to increase the maximum usage temperature of alloy IN718. A comparison of the chemical compositions of both alloys (Table 1) shows that Fe was partly replaced by Co and W.

Table 1: Chemical composition of 718Plus™, IN718 and Waspaloy in wt% [1, 2]

	C	Cr	Mo	W	Co	Fe	Ni	Nb	Ti	Al	P	B
718Plus™	0,025	18,0	2,8	1,0	9,0	10,0	B	5,45	0,7	1,45	0,014	0,006
IN718	0,025	18,1	2,9	---	---	18,0	B	5,40	1,0	0,45	0,007	0,004
Waspaloy	0,035	19,4	4,3	---	13,3	----	B	----	3,0	1,30	0,006	0,006

In addition, the Al and Ti contents and ratios were changed. The increased Al/Ti ratio in 718Plus™ leads to a higher temperature stability of the hardening phase. In contrary to IN718, where the primary hardening phase is γ'', 718Plus™ is mainly hardened by γ' [3]. The precipitation kinetics of γ' in 718Plus™ is faster than the precipitation of γ'' in IN718, but slower than the γ' precipitation in Waspaloy. The latter can be mainly attributed to the higher Nb content (718Plus™: 5,4 wt%, Waspaloy: 0 wt%), as Nb significantly lowers diffusion. γ' in 718Plus™ seems to have a higher hardening effect than γ' in Waspaloy, but a lower hardening effect than γ'' in IN718 [4]. However, the exact hardening mechanisms have not been fully understood yet and require further research work.

In the following, we want to discuss in some detail what is known about the properties of the new alloy 718Plus™. Nickel base superalloys are intended for extended periods at high temperatures. Therefore, they have to exhibit a variety of partly even conflicting mechanical properties. These are:

- High strength and high ductility
- Good crack propagation behaviour
- No notch sensitivity
- Long fatigue and creep lives

High strength is important at room as well as at high temperatures. In comparison to IN718, 718Plus™ is able to retain strength up to 704 °C [5]. This is due to the high temperature stability of its γ' phase. The use of IN718 is limited by the transformation of metastable γ'' into its stable conformation δ at a temperature of 650°C. This transformation is accompanied by a drop in mechanical properties. The tensile properties of IN718 and 718Plus™ are comparable at room temperature, but are higher for 718Plus™ at 649°C and 704°C, respectively (Table 2). Over the entire temperature range, tensile ductilities of the compared alloys are very good.

Table 2: Comparison of mechanical properties at 20 °C, 649 °C and 704 °C, respectively [6].

	Tensile Properties								
	20 °C			**649 °C**			**704 °C**		
Alloys	**YS (MPa)**	**UTS (MPa)**	**El (%)**	**YS (MPa)**	**UTS (MPa)**	**El (%)**	**YS (MPa)**	**UTS (MPa)**	**El (%)**
718Plus [A]	1204,6	1508,6	21,9	1023,2	1305,2	23,7	1005,3	1174,2	24,1
IN718 [B]	1201,8	1459,0	20,2	1008,0	1133,5	20,8	936,3	1049,2	20,3
Waspaloy [C]	1086,7	1441,1	27,0	979,1	1341,8	22,8	884,6	1087,3	38,6

[A] Heat Treatment 718Plus: 954 °C/1 h/AC + 788 °C/2 h/FC to 649 °C/8 h/AC
[B] Heat Treatment IN718: 980 °C/1 h/AC + 720 °C/8 h/FC to 620 °C/8 h/AC
[C] Heat Treatment Waspaloy: 1020 °C/4 h/OQ + 850 °C/4 h/AC + 760 °C/16 h/AC

Furthermore, for aerospace applications, it is of importance that an alloy does not show notch sensitivity. The tendency for notch breaks seems to be highly influenced by the precipitation of δ phase on the grain boundaries [4]. The quantity, as well as the morphology of δ, strongly depend on heat treatment conditions. The precipitation of a small amount of short rod-shaped δ particles on the majority of grain boundaries is believed to retard intergranular cracking and can thus prevent stress rupture notch sensitivity. At 650 °C, fatigue crack propagation of alloy 718Plus™ is slower than that of IN718 and Waspaloy. In this respect, the amount and morphology of δ phase are supposed to have a significant influence on fatigue and creep properties as well [6]. Furthermore, at high temperatures, δ phase limits grain growth as it pins the grain boundaries [7].

Apart from the mechanical properties at high temperatures, the processability and machinability, in particular weldability, are also of importance in order to ensure a cost-effective application of a material. In order to achieve good weldability characteristics, the precipitation kinetics should be rather slow, which was taken into account by Allvac when designing alloy 718Plus™ [8]. Several welding trials performed so far have shown that the weldability of 718Plus™ is similar to that of IN718 [9]. IN718 is generally considered to be an alloy with good weldability. However, it suffers from heat affected zone intergranular microfissuring. The tendency to microfissuring is attributed to liquation due to high local concentrations of B and other minor elements as well as to δ phase assisted liquation cracking [10]. As the chemical composition and thus strengthening phase and precipitation rate of 718Plus™ differ from those of IN718, it is necessary to clarify the mechanisms which determine the weldability of 718Plus™.

Although the properties of alloy 718Plus™ seem to be very promising, the new material has to be carefully tested and qualified before it can enter industrial production. Therefore, Rolls Royce Deutschland have set up an evaluation and optimisation programme for the alloy. It includes the development of a complete processing route as well as substantial mechanical testing. The latter will enable Rolls Royce design engineers to fully model and simulate material and component behaviour of alloy 718Plus™ for application in critical rotational parts like compressor and turbine discs. In addition, the materials development programme will contribute to significantly extend scientific understanding of the new alloy 718Plus™.

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