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THE RESEARCH AND DEVELOPMENT OF Nb-CONTAINING SUPERALLOY IN CHINA

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Abstract

Niobium is an important strengthening element in Fe-base, Ni-Fe-base and Ni-base superalloys. China has paid special attention on Nb in development and improvement of superalloys. An iron-base superalloy GH 4871, a modification of A-286 with 0.5~0.6%Nb, can be used as blade or disk material at 600~650°C. A systematic research and development has been conducted in China for improving the temperature capability of Nb-containing (5~5.5%Nb) Ni-Fe-base superalloy Inconel 718 (Chinese designation GH4169) from 650 to 700°C.

A Ni-base superalloy GH4133 contains 1.5%Nb with 2.5~3.0%Ti and 0.7~1.2%Al, it has been got wide application at 700°C for variety of disks in Chinese jet-engines. For economical reason the replacement of Nb for Ta is also discussed from viewpoint of strengthening in B-1900 Ni-base superalloy.

Introduction

Ni_3M, Where M can be Al, Ti, Nb or Ta, is the most important precipitation strengthening phase such as γ' or γ'' in Fe, Ni-Fe and Ni-base superalloys. Niobium has critical importance for development and application of Inconel 718 (with ~5%Nb) in today's aero-engine and gas turbine industry because of its large portion in superalloy application. Niobium has unique effect not only on precipitation strengthening of γ' and γ'' phases but also on solid solution strengthening of γ-matrix in superalloys.

China has paid special attention on niobium in development and improvement of superalloys. An iron-base superalloy GH4871* (a modification of A-286 with Nb addition) contains 0.5-0.6%Nb with 2%Ti and 0.4%Al, it can be used as blade or disk material at 600-650°C. For improving the temperature capability of Inconel 718 (Chinese designation GH4169) from 650°C to 700°C, a compact morphology or associate precipitation of γ'' and γ' structure design and chemical composition modification have been made and the alloy creep properties at 700°C show attraction for high temperature application. Nickel-base disk alloy GH4133 contains 1.5%Nb with 2.5-3.0%Ti and 0.7-1.2%Al, which has got wide application (~700°C) in Chinese jet-engines. For economical reason it is hoped, that the replacement of Nb for Ta will provide a similar strengthening effect in B1900 Ni-base cast superalloy. The research and development of above mentioned 4 Nb-containing superalloys are discussed in this paper.

* GH is Chinese designation of superalloys

Iron-Base Superalloy GH4871

15Cr-25Ni-1Mo-2Ti-Al type (A-286) iron-base superalloy is widely used in the world for power, chemical and aero-engine industries because of its economical price and good combination of mechanical properties and easy processing. With the development of high temperature technology, a new modified A-286 (15Cr-28Ni-1.5Mo-1W-2Ti-Nb-Al) with higher tensile strength and stress rupture strength at 650°C has been developed by adding Nb and W, it is designated as GH4871[1,2] in China. GH 4871 can be produced by air induction melting + electroslag remelting (AIM+ESR) or vacuum induction melting+electroslag remelting (VIM+ESR). Chemical composition of GH 4871 is shown in Table1.

Table 1 Chemical composition of GH4871 alloy (wt%)

Element	C	Mn	Si	P	S	Cr	Ni	W	Mo
Content	≤0.08	≤0.5	≤0.5	≤0.03	≤0.02	12.5~15.0	26.0~30.0	0.5~1.2	1.0~2.0

Element	Al	Ti	V	B	Ce	Nb	Fe
Content	≤0.45	1.80~2.40	≤0.30	0.005~0.02	≤0.02	0.2~0.8	bal.

Heat treatment: 980~1000°C/1~2h/OC+700~720°C/14~18h/AC

Niobium enters to γ′ precipitates — $Ni_3(Ti,Nb,Al)$, the amount of γ′ strengthening phase is increased and the stability of γ ′ phase is raised also. $Ni_3(Ti,Nb,Al)$ — γ′ phase homogeneously distributes in γ-matrix, its average size is in the rage of 10~20nm, and its weight fraction is about 3%, which is increased 1/3 in comparison with A-286. The strengthening phase γ′ is in coherence with γ-matrix and the γ′- γ lattice misfit is about 0.49%.

Tensile properties and stress rupture properties of GH4871 alloy are compared with those of A-286 alloy (GH4132) in Fig.1 and Fig.2, respectively. The stress rupture lives at 650°C of GH4871 can be improved further by vacuum melting. Fig.3 shows that not only 650°C stress rupture lives but also ductilities of VIM+ESR processed GH4871 can be raised to a higher level in comparison with AIM+ESR processed GH4871[3].

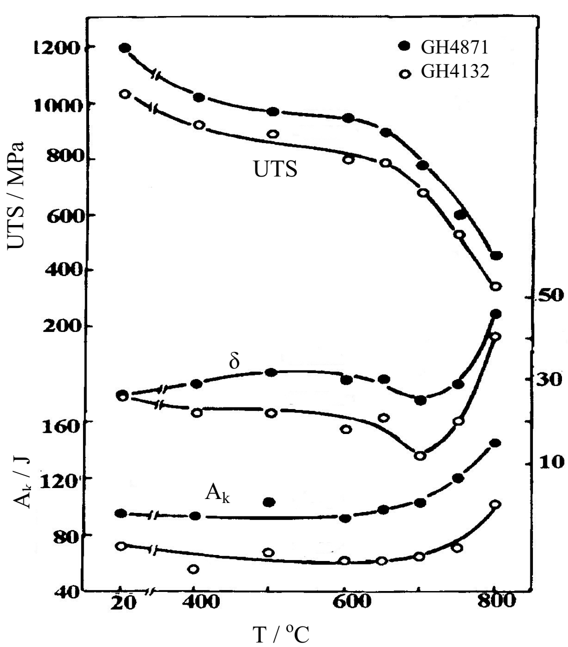


Fig.1 Tensile property comparison between GH4871 and GH4132 (A-286)

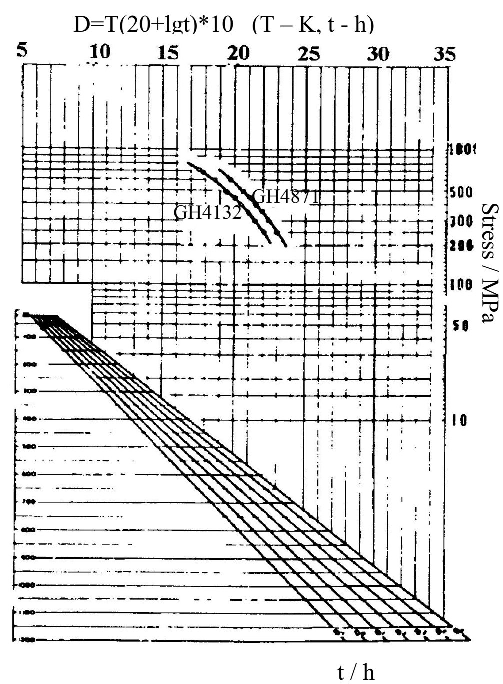


Fig.2 Stress rupture property comparison between GH4871 and GH4132 (A-286)

Fig.4 shows a comparison of strain controlled LCF properties of GH4871 in comparison with two superalloys, the 15Cr/25Ni type economical A-286 and highly alloyed Ni-Fe-base superalloy Inconel 718 (18Cr-54Ni-18Fe-5Nb-3Mo-1Ti)[4]. The LCF property of GH4871 is much better than A-286 and almost equivalent to Inconel 718. In consideration of its excellent LCF property GH4871 is suitable for disk application in power engineering.

For simulation of crack propagation behaviour at high temperature creep, fatigue and creep/fatigue interaction conditions, three kinds of loading wave forms for GH4871 were tested, which are cycling loading with 5 and 90 second dwelling times at maximum loading and with constant maximum loading condition. Fig.5 as an example shows that the 650°C crack growth rates of VIM+ESR processed GH4871 at above mentioned three loading wave forms are all lower than that of AIM+ESR processed GH4871[5]. It means that vacuum melted GH4871 is more suitable for disk application because of its good combination of strengthening and toughening.

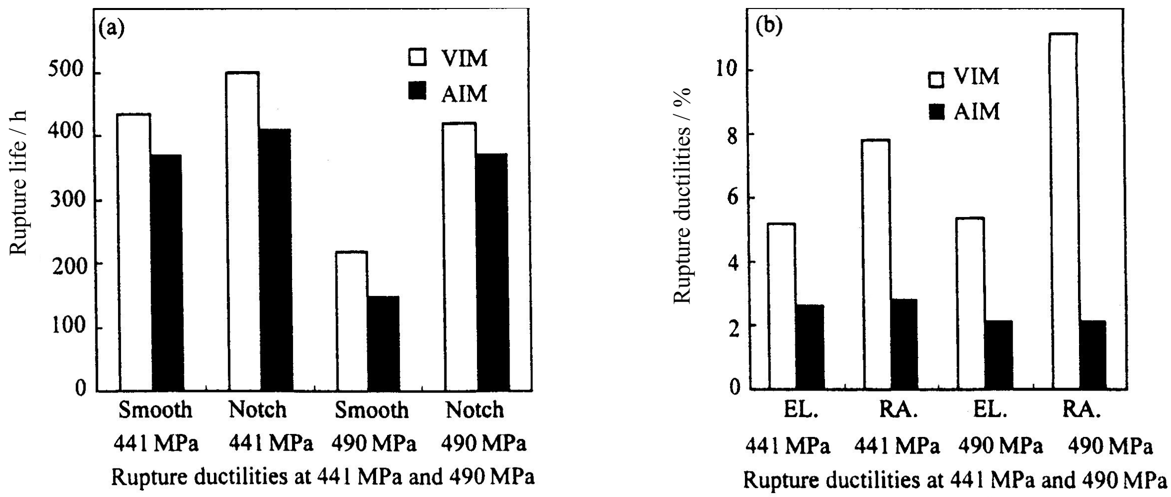
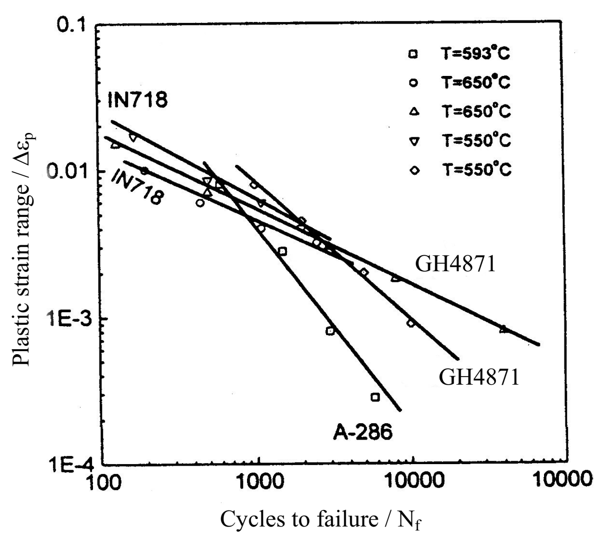


Fig.3 A comparison of 650°C stress rupture properties of air melted (AIM+ESR) and vacuum melted (VIM+ESR) GH4871 alloys



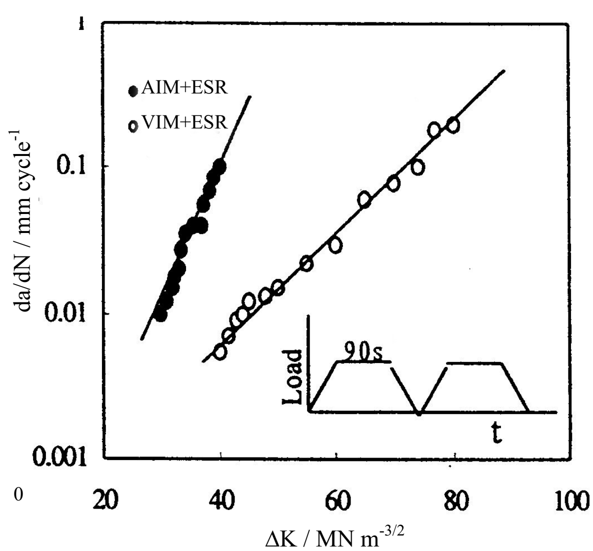


Fig.4 A comparison of LCF properties of GH4871 (AIM+ESR) with A-286 and IN718 alloys

Fig.5 Crack growth rate behaviour of air melted (AIM+ESR) and vacuum melted (VIM+ESR) GH4871 alloys at 650°C and 90 sec dwelling time at maximum loading

This modified A-286 by adding Nb and W for strengthening, designated as GH4871 was successfully developed and got industrial application in China. GH4871 characterizes with high tensile strengths, stress rupture and creep resistance, long lives to failure at low cycle fatigue and creep/fatigue interaction conditions. GH4871 has been used as blades for turbo-chargers in diesel engines. More than 600,000 blades were made of GH4871 in the years of 1988~1998. Those blades had been successfully used to assemble about 20,000 units of turbo-chargers in Tianjin Locomotive and Vehicle Plant. Some test disks were also in service for transportation industry. The great economic and social benefits were recognized in Chinese locomotive industry.

Modified Inconel 718 Alloy

Inconel 718 (Ni-19Cr-18Fe-3Mo-5Nb-1Ti-Al) containing with high fraction of Nb, strengthened mainly by Ni_3Nb type γ'' and partially by Ni_3Al type γ' precipitation is today's most widely used superalloy in the world. China has paid special attention on Inconel 718 (Chinese designation GH4169) research for alloy improvement and development. Systematic long-term research project has been conducted in close cooperation among our university, research institutes and factories[6~16,18~27]. The goal of this long-term project is in 2 steps. First step is to improve the alloy to get high quality especially for longer stress rupture lives and second step is for improving the temperature capability from 650°C to 700°C.

Alloy Improvement

The basic idea for alloy improvement is to keep the chemical composition still in the range of specification and to get the high quality alloy. The main achievements are as follows:

1. Magnesium effect[6]: The role of Mg in alloy 718 was systematically investigated in the range of 4~100ppm. The amount of main strengthening phases γ'' and γ' is not affected by Mg addition. Mg free alloy 718 (0.0004%Mg) or Mg containing alloy 718M (0.0059%Mg) both contains approximately 14% $\gamma''+\gamma'$ strengthening phases, independent of grain size. Semi-quantitative Auger analysis shows that the profile of Mg content distribution at the grain boundary regions (Fig.6). It can be seen that concentration of Mg at grain boundaries characterizes an equilibrium segregation and Mg has been further concentrated at grain boundaries during long time stress aging 526hrs at 650°C, 686MPa. Mg changes grain boundary behaviour and has grain boundary strengthening effect, especially to prolong

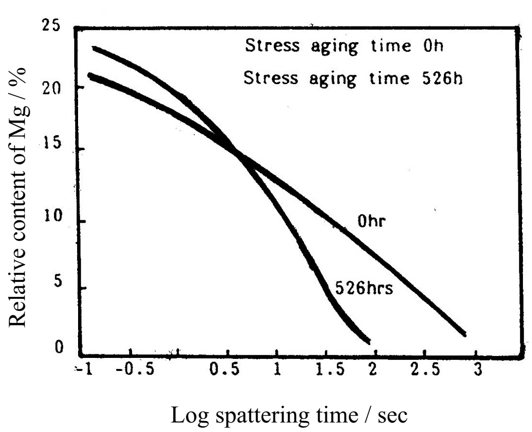


Fig.6 Grain boundary segregation behaviour of Mg in Mg-containing alloy (59ppm) 718M before and after stress aging at 650°C, 686MPa

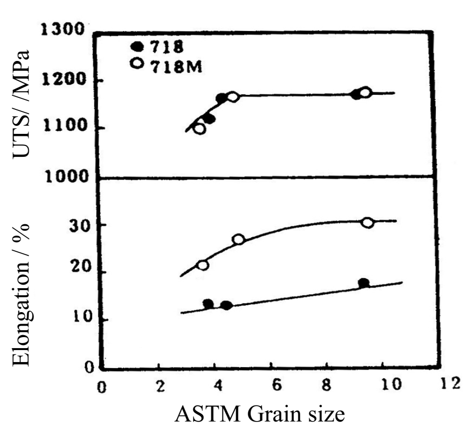


Fig.7 Mg and grain size effect on 650°C tensile properties of Inconel 718

secondary stage creep and well develope tertiary stage creep. The concentration of Mg at grain boundaries helps to change grain boundary δ–Ni_3Nb morphology in discrete globular form, which has a retardation effect on intergranular fracture. In result of that it improves ductility and characterizes with longer stress-rupture lives. Experimental results of 650°C tensile tests on different grain size experimental disks show that Mg can greatly increase ductility but has little effect on ultimate strength, which is only increased by grain refining. Mg can also remarkably increase 650°C stress rupture ductility and stress rupture lives for smooth and notched samples both (Fig.8). Cyclic stress rupture test results at 650°C with different holding times (5, 180,1800sec) at maximum stress of 686MPa show that Mg really improves cyclic stress rupture (namely stress controlled LCF with dwelling time) properties at fatigue and creep interaction conditions (Fig.9), which is important for gas turbine disk application.

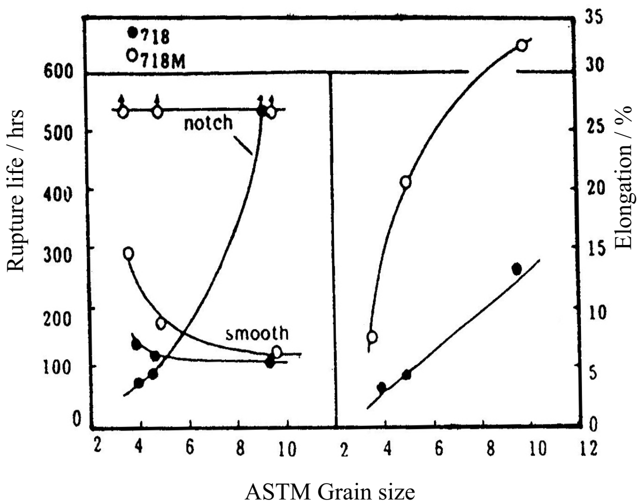


Fig.8 Mg and grain size effect on stress rupture life and elongation at 650°C, 686MPa

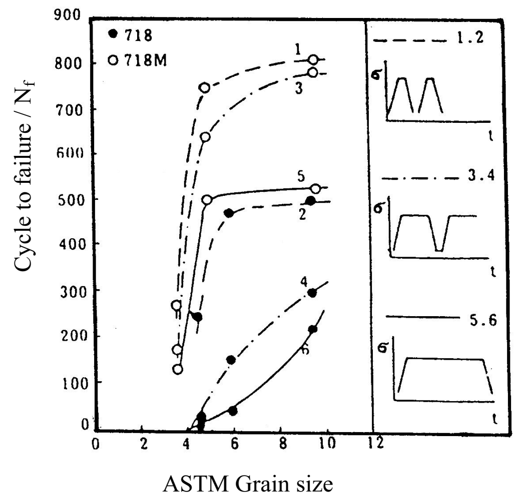


Fig.9 Mg and grain size effect on cyclic stress rupture life with different holding times at maximum stress of 686MPa, 650°C
1,2—5 sec; 3,4—180 sec; 5,6—1800 sec

2. Segregation control: Severe Nb segregation happens in Alloy 718 during solidification. In result of that the primary blocky Laves phase and eutectic Laves phase form in Alloy 718 ingot. Systematic study on the effect of trace elements on solidification has conducted in China and to develop low segregation technology by carefully control P, S, B and Si to a very low level[7]. A Φ 406mm VIM+VAR low segregation Inconel 718 ingot with very low level of phosphorus (0.0007%P) was made in production for comparison with conventional Inconel 718 (0.005%P).

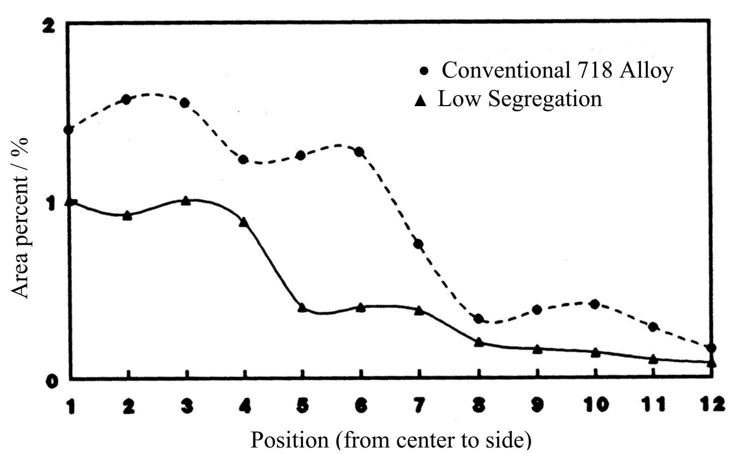


Fig.10 Distribution of blocky-Laves fraction in ϕ 406 Inconel 718 ingots

Fig.10 shows the comparison of block Laves phase fraction distribution from ingot center (point 1) to the edge (point 12) between low segregation and conventional ϕ 406mm Inconel 718 ingots. This production analysis shows that phosphorus has severe effect on the segregation of Inconel 718. However, this segregation behaviour either in low segregation or conventional ingots can be depressed by long time homogenization treatment at high temperatures. Either primary blocky Laves phase or Laves phase in eutectic can be fully dissolved in γ–matrix of Inconel 718.

3. Phosphorus effect: phosphorus is generally regarded as a most common impurity and detrimental element in superalloys. Phosphorus also severely promotes Nb segregation to form Laves phase just as above mentioned. However, systematic study on the role of P in Inconel 718 shows that phosphorus has a beneficial effect on high temperature stress rupture and creep properties[8,11~16]. Phosphorus has no influence on strengths and ductilities at room and high temperature tensile tests. However, very attractive results show in Fig.11 and 12 that phosphorus can increase stress rupture life and ductility, as well as prolong secondary creep and develop tertiary creep both. These results reveal that P has certain high temperature strengthening and ductility improvement effects. In results of that P-doping Inconel 718 development is carried out in China.

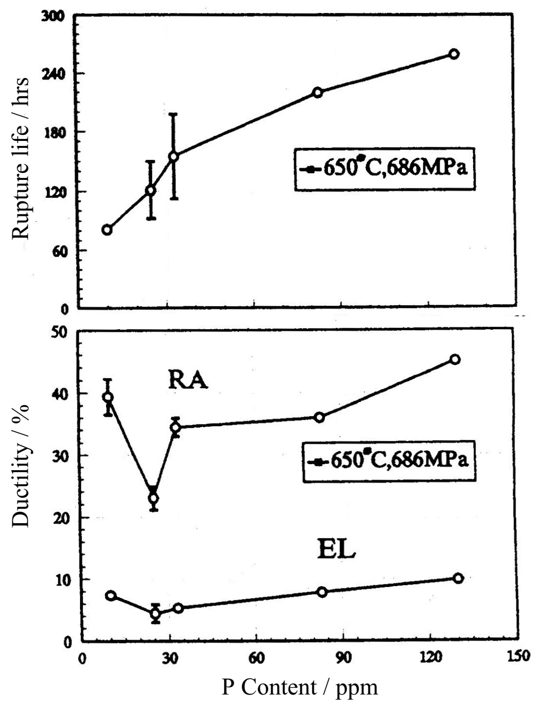


Fig.11 Effect of phosphorus on 650°C, 686MPa stress rupture life (a) and ductility (b) on IN718

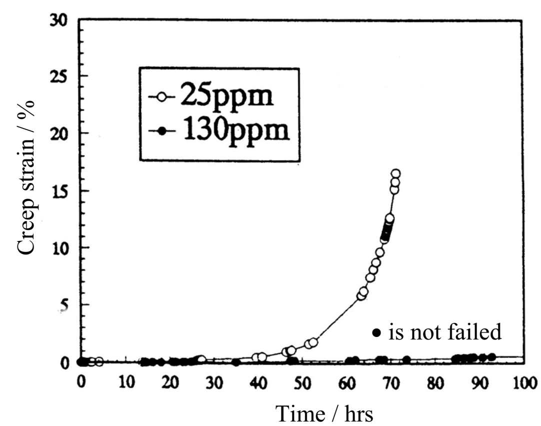


Fig.12 Effect of phosphorus on creep curves of IN718 at 650°C, 725MPa

Special attention has been paid to study the role of phosphorus in China[9,10]. Auger analyses reveal the severe concentration of P at grain boundary region (see Fig.13). Except this the solid solution strengthening alloying elements Cr and Mo also tremendously concentrate there. However, the γ″ and γ′ forming elements Nb and Ti concentrate mildly at grain boundaries as shown in Fig.13. The highest content of P at grain boundaries can reach 1% as shown in Fig.14 and the excess of Mo at grain boundaries than in γ′-matrix is also proportional to P segregation at grain boundaries.

A hypothesis is tried to suggest that grain boundary segregation of P and its interaction with different elements such as Mo may decrease gain boundary binding energy, grain boundary diffusion and increase grain boundary cohesive force. In result of that, phosphorus may effectively strengthen grain boundary to retard grain boundary sliding til to grain boundary crack at high temperature stress rupture and creep tests. A grain boundary strengthening mechanism of P is taking in consideration. However, to the best of today's knowledge, the detail mechanism of beneficial effect of P in Inconel 718 is still not clear yet.

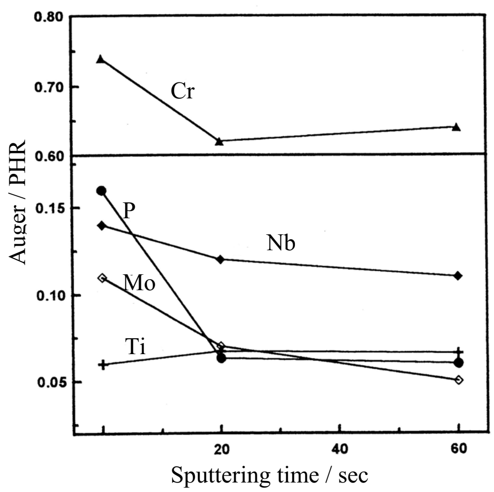


Fig.13 The concentration of P and various elements as a function of ion sputtering time from intergranular fracture surface of IN718 at auger analyses

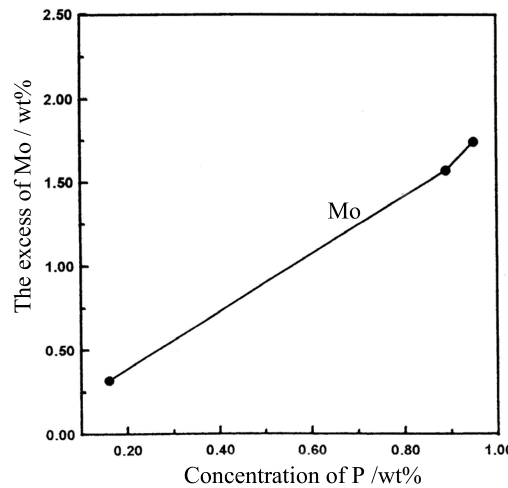


Fig.14 The relationship of Mo and P concentration at grain boundaries (in average)

Alloy Modification

One of the advances in Inconel 718 development is intended to find a modified Alloy 718 with high thermal structure stability and creep resistance to be used beyond the ceiling temperature of 650°C. K-M Chang[17] developed a new cast alloy Rene'220 on the background of Alloy 718 modification to be used at 700°C. However Rene'220 contains high fraction of Co and expensive element Ta. Nevertheless, development of wrought modified 718 Alloy to be used at 700°C was not successful. Our goal of modified 718 Alloy development is to be used as a disk alloy at 700°C. The guide lines for 718 Alloy chemical composition modification is as follows: 1. High temperature strengths (such as 700°C) especially stress rupture lives and creep properties should be almost equivalent to conventional Inconel 718 at 650°C; 2. Adjust main strengthening elements Nb, Ti and Al (no adding expensive element Ta) and keep γ'' and γ' precipitation strengthening character; 3. A small amount of solid solution strengthening elements can be added such as W and Co, but Co content is limited as low as possible; 4. Phosphorus is considered to be a new grain-boundary strengthening element as mentioned in above paragraph.

Long time structure stability study on a retired alloy 718 gas turbine disk with 28,000hrs service life[19] shows that the degradation of strengthening effect of Alloy 718 after long time stress aging is attributed to the coarsening of separately precipitated strengthening phases of γ'' and γ', and especially the rapid growth of γ'' precipitates at higher temperatures because of its high lattice misfit between γ''/γ' and high coherency strain energy also. It will be worse that fine dispersively precipitated meta-stable phase γ'' transforms to large plate-like stable phase δ-Ni_3Nb after long time service at high temperature.

From view point of γ″ and γ′ precipitation strengthening a modified Inconel 718 with high content of Al+Ti+Nb (in at%) can precipitate high fraction of γ″+ γ′ precipitates for high strengthening as shown in Fig.15[23].However, it must be acceptable in routine production.
Detailed TEM study reveals that, most of γ″ and γ′ precipitate separately from γ-matrix during the aging and intensively grow especially the main strengthening phase γ″at high temperatures in conventional 718 Alloy. For thermal stability improvement of γ″, two types of combined precipitation of γ″ and γ′ are designed in modified 718 alloys[20~22].

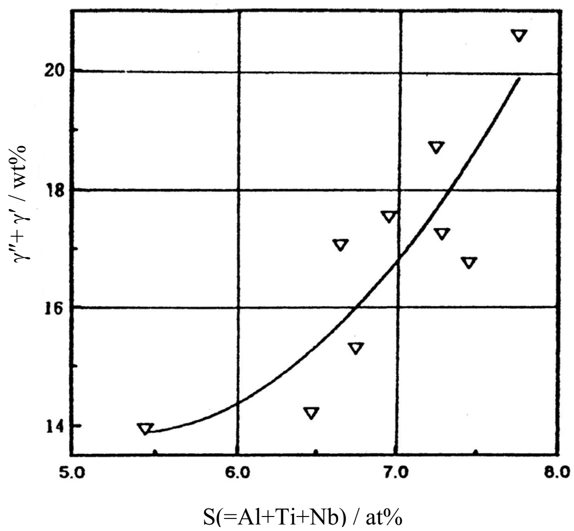


Fig.15 Relationship of (Nb+Ti+Al)% and γ″+γ′% in modified 718 alloys

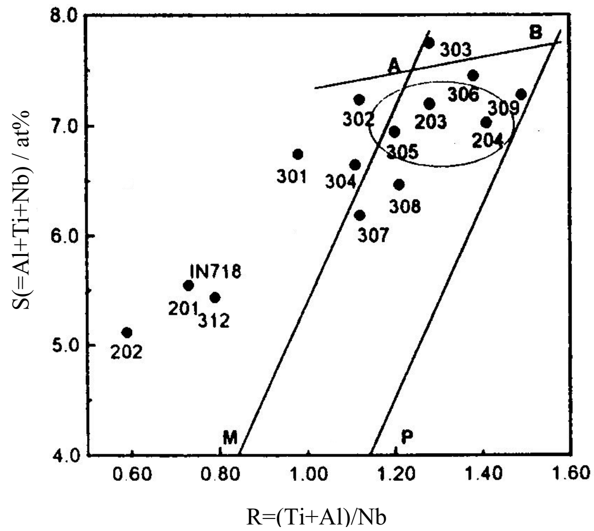


Fig.18 Chemical composition distribution of modified 718 alloys in S-R coordinate

1. Associated precipitation of γ″ and γ′. γ″ can be bound up with almost hemispherical γ′ or can alternatively precipitate as a “sandwich” morphology as show in Fig.16 (a) and (b).

2. Compact morphology of γ″ and γ′. γ″ can directly precipitate at cuboid shaped γ′particles coated with its shell as shown in Fig.16 (c) and (d). A typical high resolution electron microscopy image of compact morphology of γ″ and γ′ is shown in Fig.17.

Associated precipitation and compact morphology of γ″ and γ′ can be formed in modified 718 alloys with higher contents of Al and Ti respectively (>1.0 wt%) and higher atomic ratios of (Al+Ti)/Nb and Al/Ti at different levels of Nb from 4.75, 5.1 to 5.5 wt%. However, γ″ and γ′ separately precipitate from γ-matrix in conventional 718 Alloy with lower contents of Al (~0.5%) and Ti (~1.0%) and lower atomic ratios of (Al+Ti)/Nb=0.70 and Al/Ti=0.79.

Fig.18 is adopted from Pineau’s diagram that in the range of MABP γ″ and γ′ can co-precipitate in associate precipitation or in compact morphology form. Our results show that at higher sum of Al+Ti+Nb% and higher ratio of (Al+Ti)/Nb can promote γ″+ γ′ associate precipitation and their compact morphology as circled in Fig.18[23]. However, when chemical composition modification is in the range above the AB line, the modified 718 alloys is very difficult to forge because of very high content of Al+Ti+Nb and high atomic ratio of (Ti+Al)/Nb. The location of conventional 718 alloy with separate precipitation of γ″ and γ′ as indicated in the very left part of Fig.18

700°C creep tests on modified 718 alloys are very attractive, that creep fracture lives at 700°C and different stresses (500~600MPa) increase with the atomic sum of Al, Ti and Nb reach the peak at Al+Ti+Nb=7, then mildly decrease again with Al+Ti+Nb increases further (see Fig.19a). In consideration of the complex effect of Al+Ti+Nb a coefficient of $K= \sqrt{Al + Ti/Nb)^2 + (Al/Ti)^2} \bullet Nb$ is suggested for creep rupture lives evaluation. Creep rupture lives are almost proportional to the coefficient K at the stress levels of 500, 550 and 600MPa for 700°C (Fig.19b). Creep rupture lives of modified 718 alloys are longer than conventional 718 alloy. It indicates that associated precipitation and compact morphology of γ″ and γ′ in modified Alloy 718 with higher Al+Ti+Nb content and higher ratios of (Al+Ti)/Nb and Al/ Ti posses with not only higher thermal stability but also longer creep rupture life.

For the enhancement of solid solution strengthening except molybdenum (~3%Mo) a small amount of tungsten (1~2%W) has been also added in modified 718 alloy[24~27]. It can decrease diffusion in γ-matrix and simultaneously to increase the thermal stability of γ″ and γ′. For stronger solid solution strengthening effect and enhancement of the stability of γ″ and γ′ a lower level of cobalt is going to be added in the modified 718 alloy.

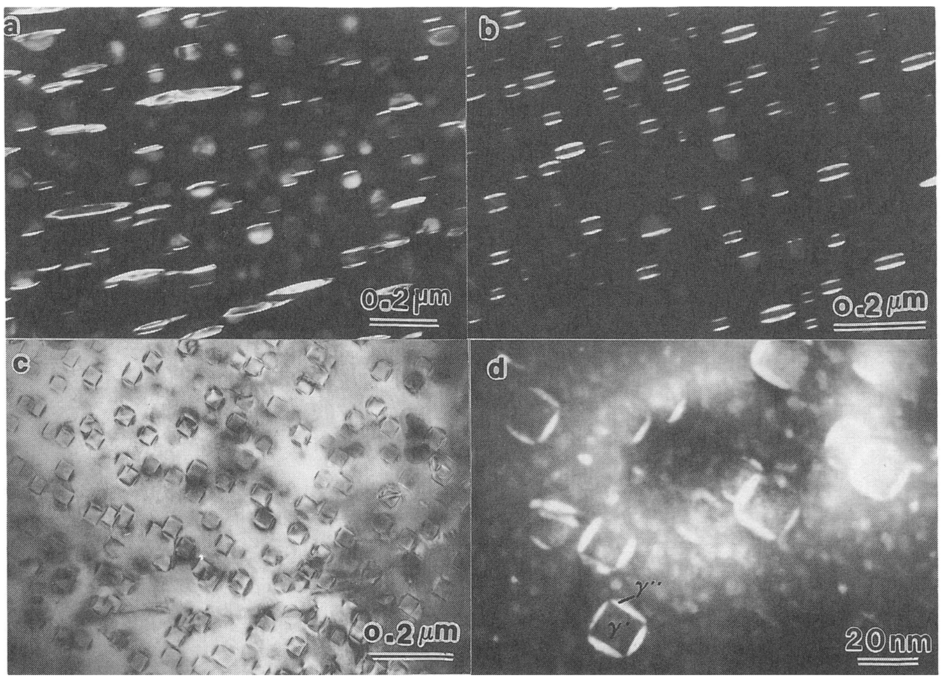


Fig.16 Associated precipitation and compact morphology of γ″ and γ′ in Alloy 13 (a-dark field) and Alloy 15 (b, d-dark field, c-bright field) after long time aging at 730°C for 200hrs

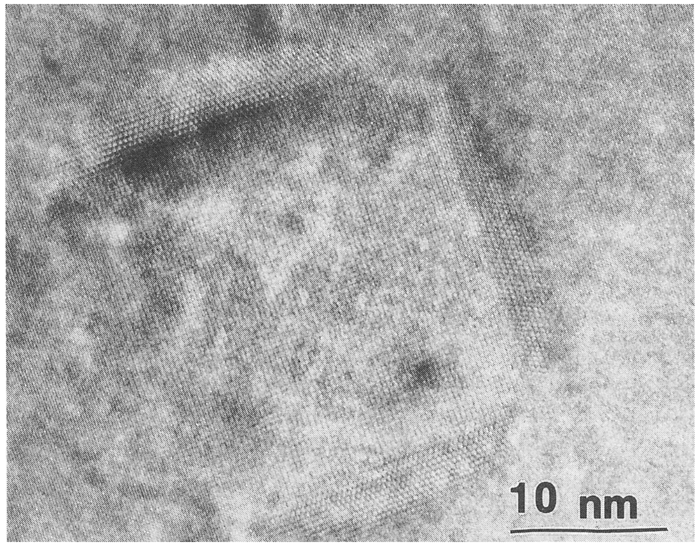


Fig.17 HREM image of compact morphology of γ″ and γ′
in Alloy 15 after long-time aging at 730°C for 200hrs

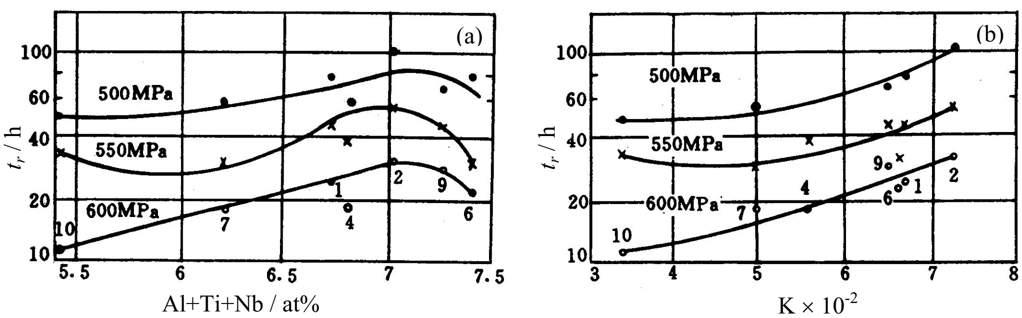


Fig.19 Dependence of 700°C creep fracture time on atomic sum
of Al+Ti+Nb (a) and on coefficient K at 500, 550, 600MPa (b)

A new modified Inconel 718 alloy to be used at 680~700°C for disk application is developing in China. This new modified alloy is based on of Ni-19Cr-18Fe-3Mo-B, with high level of Nb (5.2~5.5 wt%Nb). The sum of Nb+Al+Ti is controlled in the range of 6.5~7.5 at% and the atomic ratio of (Al+Ti)/Nb keeps in the interval of 1.1~1.4, 1~2% (wt%) W and occasionally a lower level of cobalt are to be added for the enhancement of solid solution strengthening effect and a certain amount of phosphorus (100~150ppm) is accepted as grain-boundary strengthening element in this new modified 718 alloy. The research and development of this new modified 718 alloy is going on the National High-Tech Project Program in close cooperation among research institutes, university and factories.

Nickel-Base Superalloy GH4133

A China invented γ′ precipitation strengthening nickel-base superalloy containing with 1.5%Nb designated as GH4133[28~30] had been put in production for more than 20 years. GH4133 is widely used in China for variety of disks in different jet-engines at the service temperatures below 700°C. Chemical composition of GH4133 is shown in Table 2.

Table 2. Chemical composition of GH4133 in wt%

Element	C	Cr	Al	Ti	Nb	Fe	B	Ce	Mg	Zr	Ni
Content	≤0.07	19~22	0.70~1.20	2.50~3.00	1.15~1.65	≤1.5	≤0.01	≤0.01	0.001~0.1	0.01~0.1	bal.

Heat treatment: 1080°C/8h/AC+750°C/16h/AC

GH4133 is simply based on Ni-20Cr γ-matrix strengthened with γ′-forming elements Al, Ti and Nb and certain amount of trace elements such as B, Ce, Mg, Zr. Typical structure of GH4133 at as heat treated condition is γ-matrix with 14~15% γ′-Ni_3(Al,Ti,Nb) phase , which is $(Ni_{0.94}Cr_{0.06})_3(Al_{0.42}Ti_{0.47}Nb_{0.11})$ in chemical composition. A small amount of grain-boundary carbide $M_{23}C_6$ is beneficial for grain-boundary strengthening and MC type carbide (Nb,Ti)C is also found in this alloy.

The main strengthening phase γ′ is in average size of 200Å. At long time aging til to 2000hrs at 700°C, GH4133 possesses very stable structure.

Detail study on the role of Nb in GH4133 reveals that Nb dissolves in γ, γ′ and MC phases, the distribution of Nb in γ, γ′ and MC is roughly in 5:3:1 proportion as shown in Fig.20. The atomic size of Nb is larger than Ni in γ-matrix and also larger than Al and Ti in γ′ phase. The solution of Nb in γ-matrix causes lattice distortion and enhances solid solution strengthening. The solution of Nb in γ′ phase increases not only the lattice parameter of γ′ but also increases the long range order of γ′ (see Fig.20) with raising APB energy (antiphase boundary energy) for blocking dislocation cutting through γ′ order precipitates. Based on dislocation strengthening mechanism, the strengthening effect in yield stress increment is basically in good agreement with the experimental results (see Fig.21).

For high temperature ductility (especially stress rupture ductility) improvement, which is important for creep and crack propagation properties in disk application, a small amount of Mg (0.001~0.01%) and Zr (0.01~0.1%) are added in GH4133 for further improvement. Fig.22 shows that Mg can prolong secondary creep stage and intensively develop tertiary creep stage to reach higher stress rupture ductility and longer stress rupture live and also to improve LCF and crack propagation properties at high temperature creep and fatigue interaction conditions.

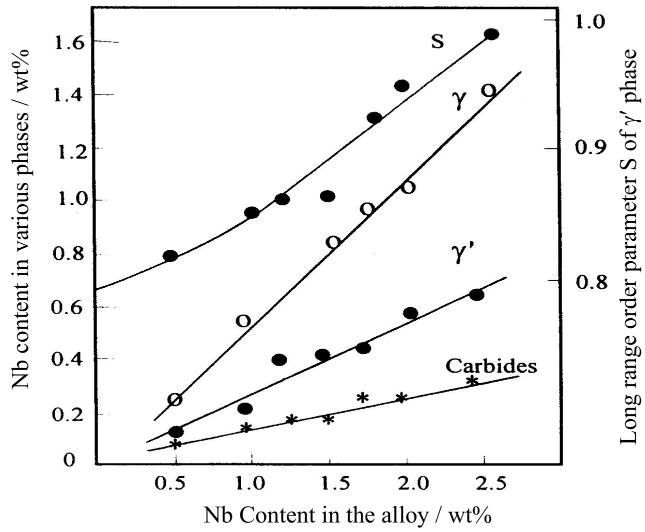


Fig.20 The distribution of Nb in γ, γ′ and carbides and the effect of Nb on long range order parameters of γ′ phase

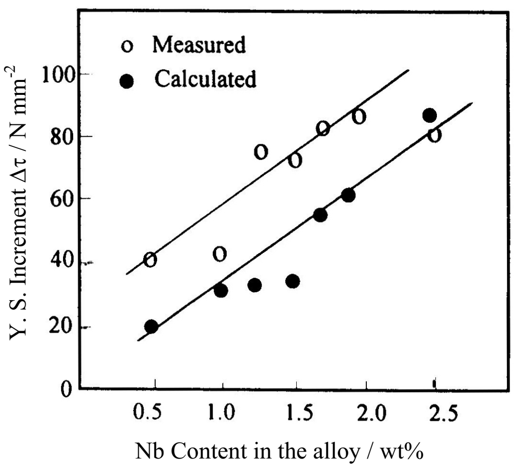


Fig.21 The effect of Nb on yield strength (Y. S.) increment

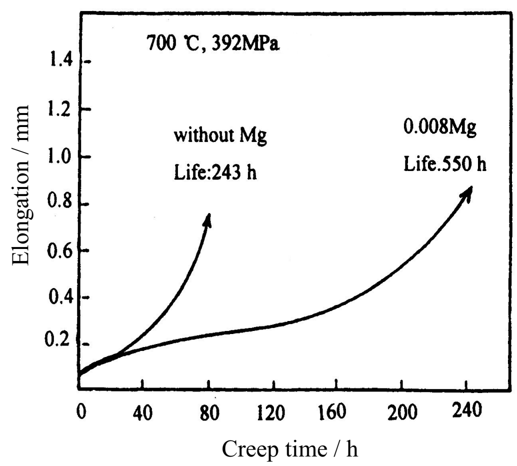


Fig.22 The effect of Mg on creep curves of GH4133

Strengthening Effect of Nb in B-1900

Tantalum has beneficial effect on increasing high temperature strength and hot corrosion resistance in nickel-base superalloys. A number of high performance nickel-base superalloys contain less or more tantalum, sometimes even up to 10%Ta. However, Ta is not only an important strategic metal but also has supply shortage in China and its price is very expensive.
Niobium is at same column of periodical table of elements. An idea and also a question have been raised that is it possible to use Nb for replacement of Ta in Ni-base superalloys. An attempt was made to study the role of Ta and Nb in a modified cast nickel-base superalloy B-1900 on the base of Ni-8Cr-10Co-6Mo-6Al-1Ti with various additions of tantalum (0~4.3 and 6.4%Ta) and niobium (0~4.3%Nb)[31].

The tensile properties, stress rupture properties and creep curves at 760°C of the alloys with various contents of Nb are shown in Fig.23, 24 and 25 and in comparison with various Ta addition alloys. The atomic equivalent amount of Nb increase the tensile strength, stress rupture strength and creep resistance as similar as Ta does. Both 700°C tensile and creep ductilities are enhanced, but the increment of creep ductility by Nb addition is not so large as in case of Ta. From the viewpoint of improving strength and ductility, it is possible to make substitution of Nb for Ta.

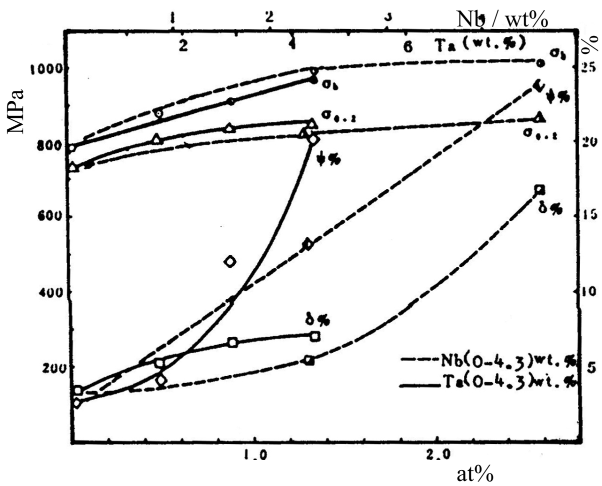


Fig.23 The influence of Ta and Nb in alloys on tensile properties at 760°C

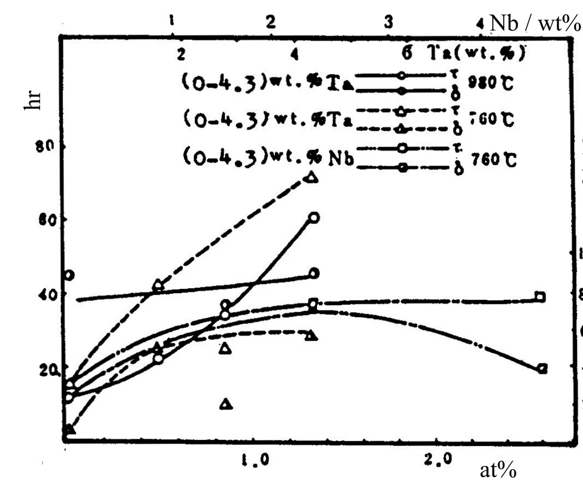


Fig.24 The influence of Ta and Nb in alloys on stress rupture properties at 760°C, 647MPa; 980°C, 200MPa

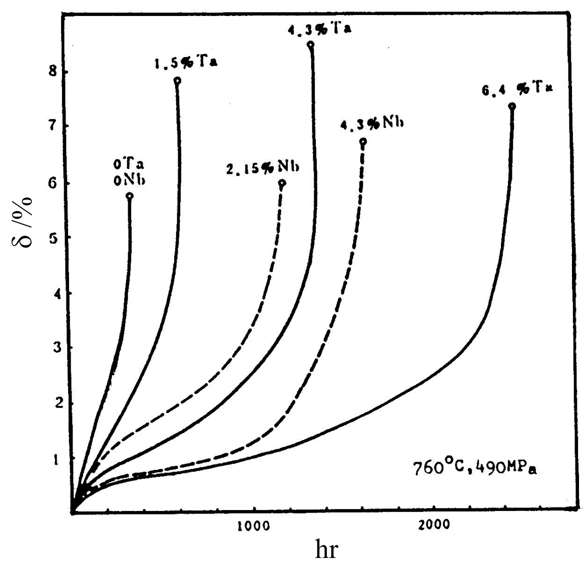


Fig.25 The creep curves of alloys with various contents of Ta and Nb

Conclusions

Niobium is considered to be an important strengthening element in development of Chinese superalloys. Niobium mainly distributes in γ-matrix and Ni_3M type γ′ or γ″ strengthening phases and has not only strong precipitation strengthening effect but also important solid solution strengthening effect and a partial amount of niobium can be combined in carbide such as MC. The main achievements of the research and development of Nb-containing superalloys described in this paper are as follows:

1. An iron-base superalloy GH4871 (a modification of A-286 with Nb addition) contains 0.5~0.6%Nb with 2%Ti and 0.4%Al, it can be used as blade and disk material at 600~650^{o}C.

2. A new modified Inconel 718 is based on Ni-19Cr-18Fe-3Mo-B with high level of Nb (5.2~5.5%Nb). The sum of Nb+Ti+Al is controlled in the range of 6.5~7.5at% and the atomic ration of (Al+Ti)/Nb keeps in the interval of 1.1~1.4, 1~2%W and occasionally a lower level of cobalt are to be added for the enhancement of solid solution strengthening and a certain amount of phosphorus (100~15ppm) is accepted as grain boundary strengthening element in this alloy. This new modified Inconel 718 is designed to be used at 680~700^{o}C for disk application.

3. A China invented nickel-base disk alloy GH4133 contains 1.5%Nb with 2.5~3.1%Ti and 0.7~1.2%Al can be used at 700^{o}C and has got wide application in Chinese jet-engines.

4. For economical reason it is hoped, that the replacement of Nb for Ta will provide a similar strengthening effect in B-1900 Ni-base cast superalloy.

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