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High temprature resistant material and its application: A Review

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Abstract:**This paper presents an overview of high temperature resistance material properties and its applications. There are many alloys developed for high temperature resistance but out of majority of high temperature resistance alloys Ni & Ti taken under consideration due to the fact that both alloys are high corrosion alloys and both have the applications in aerospace industries. These alloys are widely used as high temperature material for turbine blades in aerospace industry and land base applications. Nickel based alloys have poor machinability. After discussing about Nickel based alloy in this review paper we discussed about the Titanium alloys also which are also used as a high temperature alloys also. The addition of Silicon in titanium alloysincreases the strength of these alloys rapidly.**

I. Introduction

The alloys which can resist temperature more than 1000 F are called high temperature resistance material. Nowadays the development of high temperature alloys and super alloys are the new challenge for industries. These materials have many applications in air crafts, land base turbine, boilers, internal combustion engine and especially used in air craft turbine blades because these components are subjected to extreme external load conditions at high altitude.

Many industries have benefit from higher operating temperatures.
Higher temperature operation has a powerful effect on the performance of the gas turbine engine. For example an increase of 150^0C in turbine entry temperature combined with elimination of internal air cooling of turbine components can give an improvement of around 6% in gas generator thermal efficiency [21]. The temperature of superheater tubes for steam-raising boilers in power plants is currently 560^0C if this could be increased to 650^0C efficiency would increase from 35% to 36.5%. This would result in a saving approx 3.5 x 10 6 t of coal per year, i.e. 4% of the total coal used in the United Kingdom for power generation [22].

The temperature resistance capability of alloys varies with the composition of different metals. The following table1 shows the temperature resist capability of some alloys [1].

TABLE 1: TEMPERATURE RESIST CAPABILITY OF SOME ALLOYS [1]

S. No.	Material	Approx. max.use temperature (deg C)
1	Aluminium (RR350)	300
2	Low-alloy steel	580
3	Ti-1100	600
4	Nickel superalloy	1000
5	Nickel (Brightray H)	1250
6	Alumina	1850
7	Tungsten	2500

II. Nickel based alloys

Nickel based alloys are very important material for high temperature applications in aerospace and power generation industries due to its corrosion resistance, high strength and creep strength.[2] Nickel based superalloy containing high Cr and Al forms a protective oxide films such as Cr2O3 and Al2O3 to maintain corrosion resistance even at high temperature.[3,4]Nickel based high temperature alloy comprise about 30% of total material requirement in the manufacturing of an aircraft engine[5] and currently comprise 50% of the weight of advance aircraft[6].Nickel based superalloys are also used in engine components where the required operating temperature is above 800 ^{0}C [7].

The subsequent development of nickel alloys had two objectives:
(1) increased oxidation and corrosion resistance.
(2) increase of strength and temperature capability.

The following table 2 of some nickel based superalloys with information of their composition.

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TABLE 2: COMPOSITION OF NICKEL BASED ALLOYS [8]

S.No.	Alloys	Ni	Cr	Fe	Al	Mo	Ti
1	Inconel 600	76.0	15.0	8.0	-	-	-
2	Inconel 601	60.0	23.0	14.4	1.4	-	-
3	Inconel 718	54.0	18.0	18.5	-	3.0	-
4	Incoloy 800	32.5	21.0	46.0	-	-	-
5	Incoloy 825	42.0	21.5	28.0	-	3.0	1.0
6	Inco Hx	47.5	21.8	18.5	-	9.0	-
7	Nimonic 75	80.0	19.5	-	-	-	-
8	Nimonic 263	51.0	20.0	-	0.5	5.8	2.2
9	Nimonic 901	42.4	12.5	36.0	-	5.8	2.9

Where

Inconel: An alloy of nickel chromium and iron.

Incoloy: A range of super alloys produced by special Metal Corporation.

Nimonic: A registered trademark of Special metal Corporation.

Machineability of Nickel based alloys

Nickel based high temperature alloys are very difficult to machine due to the strength of these alloys. The cutting forces and temperature of cutting area is too high because of high stress developed at machining area and also due to the low thermal conductivity of material[9]. All these properties of alloys contribute to low material removing rate and short life tool which result huge machining cost.

Milling is the major operation carried out in the manufacturing of jet engine mounts and blades for the compressor of jet engine [8].

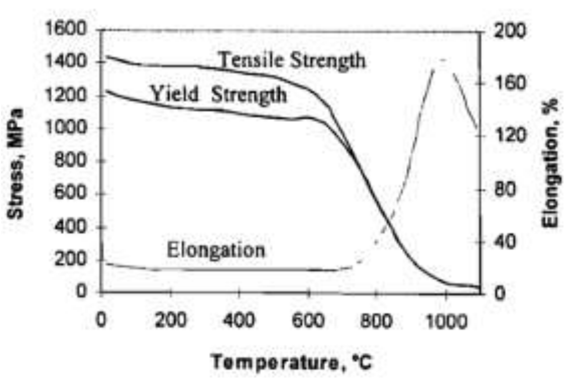

Fig 1: High and low temperature properties of Inconel 718 [8]

The machining on Nickel alloys are carried out on low speed approximately 20-30 m/min and feeds 0.15 mm/tooth by the using of Carbide[8].

Carbides are most widely used tool material for machining of Nickel alloys due to its toughness and resistance to thermal shock[8].

Properties responsible for the poor machineability of Nickel based alloys [20].

- The poor thermal conductivity leads to high cutting temperature up to 1200 ^{0}C at rake face.
- The highly abrasive carbide particle contained in the microstructure cause abrasive wear.
- Due to their high strength, the cutting forces attain high values, excite the machine tool system and may generate the vibrations which comprises the surface quality

.

III. TITANIUM ALLOYS

Titanium has exceptional properties of strength, corrosionresistance, workability and weldability [10]. No other material approaches this combination of engineering properties over a temperature range spaning from ambient temperature to about 550 deg C [10]. Titanium melts at a temperature of 1668 deg C, an indication that titanium will exhibit good creep strength over a large range of temperature [11]. Because of all these properties of Titanium alloy started widely used for air craft as a material having light weight (density being 60% of that steel) high strengthand excellent corrosion resistance [12].Titanium alloys has a high compatibility with carbon fibre reinforced plastic (CFRP), which is used in large amounts in place of aluminium alloy to reduce in airframe weight and thus to improve fuel economy [13]. This material is popular in aero enginedesign and the use of Titanium alloy has been increased from 3% to 31% of the aero engine weight since 1950 [10].The Titanium alloy is also used in the various parts ofairframe. The following table 3 is about the application of Titanium alloys in airframe.

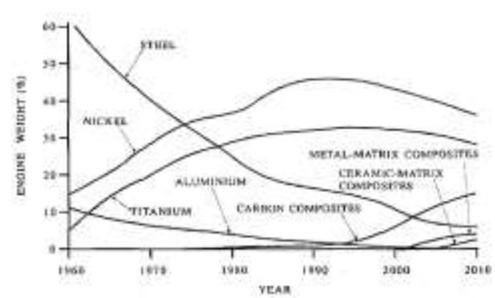

Figure 2:Evolution of material used in aero engine turbine [10].

TABLE 3: APPLICATION OF TITANIUM ALLOYS IN AIRFRAME. [12]

S.No.	Material	Example of application
1	Ti-6Al-4V	Cockpit window frame, wingbox, Fasteners
2	Ti-3Al-2.5V	Hydraulic pipe
3	Ti-10V-2Fe-3Al	Landing gear, Track beam
4	Ti-6Al-2Sn-4Zr-2Mo	Exhaust, Tail cone
5	Ti-15V-3Cr-3Sn-3Al	Duct

The high strength to density ratio of titanium makes it a very attractive design. In the following table 4 temperature range and chemical composition of high temperature Titanium alloy is listed in order of introduction. [14]

TABLE 4: TEMPERATURE RANGE AND CHEMICAL COMPOSITION [14]

S. No.	Alloy designation	Max temperature	Al	Sn	Zr	Mo	V	Si
1	Ti-64	300	6	-	-	-	4	-
2	IMI-550	425	4	2	-	4	-	0.5
3	Ti-811	400	8	-	-	1	1	-
4	IMI 679	450	2	11	5	1	-	0.2
5	Ti-6246	450	6	2	4	6	-	-
6	Ti-6242	450	6	2	4	2	-	-

IV. ADDITION OF SILICON TO TITANIUM

Silicon(Si) is an important element in high temperature titanium alloys since it is increased strength at all temperatures and has a marked beneficial effect on creep resistance [15]. The improvements in properties of Ti-Si alloys are to be related to its microstructure. The increased strength of Ti-Si alloys is increased to the peak then it started decrease [11]. The following Table [11] displaying the effect of Si addition on tensile properties of Ti-Si alloys.

TABLE 5: EFFECT OF SI ADDITION ON TENSILE PROPERTIES OF TI-SI ALLOYS.

S.No.	Si (Wt%)	Ultimate tensile strength (Mpa)	Yield strength(Mpa)	Elongation(%)
1	0.0	315	207	30
2	0.6	535	423	21
3	1.0	686	608	18
4	2.0	780	726	1.0
5	3.0	589	-	<1.0
6	4.5	711	687	0.7
7	6.5	834	736	0.8
8	8.5	775	726	0.4

The elongation in the Ti-Si alloy decreases with the increment of Si weight percentage. Increased silicon addition may results in yield strength and ultimate tensile stress accompanied by undesirable decrease in fracture toughness [16]. Silicon also play a protective role in oxidation of titanium alloys [11].

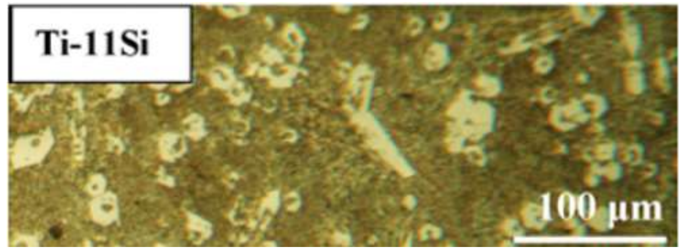

Figure 3: Optical Micrographs of the cross section of Ti-Si rod [17].

The addition of bismuth (Bi) in small quantities to Ti-Si alloys may overcome this degradation on ductility, without sacrificing strength [17].

The role played by Silicon in Ti-Si alloys are following.

• Silicon reduces the penetration depth of oxygen into alloy substrate

• Silicon, dissolved in a titanium oxide surface layer, reduces the diffusion rate of oxygen through this layer.

• Silicon modifies the stress relaxation processes in the oxide layer, leading to a more compact scale with lower porosity.[18,19]

The rate of oxidation in Ti alloys is significantly reduced due to the addition of silicon; however this reduction is not proportional to the silicon concentration within the alloy

V. CONCLUSION

1. Successfully studied the need of high temperature alloys and its application.
2. Nickel and Titanium both alloys are widely used in the aerospace industries.
3. The major reason of poor machinability of Nickel based alloy is that during machining of these alloys high temperature generates in cutting zone which effect in thermal softening of tool.
4. Titanium alloys is also started using in the air crafts because of its light weight and high corrosive resistance.
5. Addition of Silicon increases the strength of Titanium at high temperature and reduces the rate of oxidation.

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