INDUSTRIAL APPLICATIONS OF HEAT RESISTANT MATERIALS

- For high temperature applications, proper alloy selection is important for safety and economic reasons.

- Since all high temperature materials have certain limitations, the optimum choice is often a compromise between the mechanical property constraints (creep and stress rupture strength), environmental constraints (resistance to various high temperature degradation phenomena), fabricability characteristics, and cost.

1. HEAT TREATING FURNACE PARTS AND FIXTURES:

- The many parts used in industrial heat treating furnace can be divided into two categories.

  - The first consists of parts that go through the furnaces and are therefore subjected to thermal and/ or mechanical shock: trays, fixture, conveyor, chains and belt, and quenching fixture.

  - The second comprises parts that remain in the furnace with less thermal or mechanical shock: support beams, hearth plates, combustion tubes, burner, rotary retorts, pit type retorts, muffles etc

- The great majority of heat-treating furnaces use iron-chromium-nickel or iron-nickel-chromium alloys because the straight iron-chromium alloys do not have sufficient high temperature strength to be useful.

- Because some iron chromium alloys (more than 13% Cr) are susceptible to so called 475^{o}C embrittlement.

- Because of increasing temperature (>980^{o}C) more and more application use nickel base alloys for their improved creep rupture strengths and oxidation resistance.

- Cobalt base alloys are generally too expensive except for very special application.

- In general, these materials contain iron, nickel and chromium as the major alloying elements. Nickel influences primarily high temperature strength and toughness. Chromium increases oxidation resistance by the formation of a protective scale of oxide on the surface. An increase in carbon content increase strength.

2. RESISTANCE HEATING ELEMENTS:

- Resistance heating alloys are used in many varied application from small household appliance to large industrial process heating systems and furnaces.

- In industrial furnaces, elements often must operate continuously at temperature as high as 1300^{o}C for furnaces is used in metal treating industries, 1700^{o}C for kilns used for firing ceramic, and occasionally 2000^{o}C or higher for special applications.

- The primary requirements of materials used for heating elements are high melting point, high electrical resistivity, good oxidation resistance, absence of volatile components and resistance to contamination.

- Other desirable properties are good elevated temperature creep strength, high emissivity, low thermal expansion, good resistance to thermal shock, and good strength and ductility at fabrication temperatures.

- Nickel-chromium and nickel-chromium-iron alloys are the most widely used heating materials in electric heat-treating furnaces.

- The 80Ni-20Cr alloys are more commonly used than the 60Ni-16Cr-20Fe or the 35Ni-20Cr-45Fe types. Because they have the greatest resistance to oxidation, and therefore can be used at higher temperatures.

- The iron-chromium-aluminum alloys are widely used in furnaces operating at 800 to 1300^{o}C. In general, Ni-Cr heating elements are unsuitable above 1150^{o}C because the oxidation rate in air is too great and the operating temperature is too close to the melting point of the alloy.

- Fe-Cr-Al elements can generally be used at high temperatures than Ni-Cr elements.

- For temperatures above 1300^{o}C, silicon carbide or molybdenum disilicide elements are employed in industrial furnaces.

- Molybdenum disilicide elements are excellent oxidation resistance, long life, constant electrical resistance and resistance to thermal shock.

- These nonmetallic materials give fair service life in slightly reducing atmospheres at temperature up to 1300^{o}C for SiC and 1500^{o}C for $MoSi_2$.

- They can be used in both oxidizing slightly reducing atmospheres more commonly than Fe-Cr-Al elements, which are recommended only for service in air or inert atmospheres.

- Platinum has been used in some small special laboratory furnaces up to 1480^{o}C in air. Because of the high cost of platinum, it is used only in special applications. Platinum is restricted to service in air and cannot be used in reducing atmospheres.

- Elements made of 90% molybdenum disilicide and 10% refractory oxide mixtures perform well at continuous temperatures of 1700 and 1800^{o}C in air and in other oxidizing or inert atmospheres.

3. HOT WORKING TOOLS:

- Materials for hot-working tools (e.g., forging anvils and dies, extrusion dies, hot shear blades) require high hot hardness, ability to withstand impact stresses and thermal shock, and adequate abrasion resistance.

- The most commonly used materials are the hot-work tool steels with about 0.4%C and various addition of tungsten, chromium, vanadium, molybdenum, and cobalt. These steels maintain a high resistance to deformation up to about 550 to 600^{o}C.

- The important factors are the temperature of the tool, the time at temperature, and the strength of the work material.

- Even in cases where tool steels give satisfactory performance, advantage can often be gained by using superalloy tools whose longer life offsets the increased cost.

4. HIGH TEMPERATURE SERVICE BEARINGS:

- Rolling-element bearings are fabricated from a wide variety of steel.

- Bearing steels can be divided into two classes: standard bearing steels are intended for normal service conditions (maximum temperatures are of the order of 120 to 150^{o}C); where as special-purpose bearing steels are used for either extended fatigue life or excessive operating conditions of temperature and corrosion.

- When bearing service temperatures exceed about 150^{o}C, common lower-alloy steels cannot maintain the necessary surface hardness to provide satisfactory fatigue life.

- Table lists the compositions of certain bearing steels suited for high-temperature service. These steels are typically alloyed with carbide-stabilizing elements such as chromium, molybdenum, vanadium, and silicon to improve their hot hardness and temper resistance.

Nominal compositions of high-temperature bearing steels

Steel	Composition, %								Maximum operating temperature(a)	
	C	Mn	Si	Cr	Ni	Mo	V	Other	°C	°F
M50	0.85	...	...	4.10	...	4.25	1.00	...	315	600
M50-NiL	0.13	0.25	0.20	4.20	3.40	4.25	1.20	...	315	600
Pyrowear 53	0.10	0.35	1.00	1.00	2.00	3.25	0.10	2.00 Cu	205	400
CBS-600	0.19	0.60	1.10	1.45	...	1.00	...	0.06 Al	230	450
Vasco X2-M	0.15	0.29	0.88	5.00	...	1.50	0.5	1.50 W	230	450
CBS-1000M	0.13	0.55	0.50	1.05	3.00	4.50	0.40	0.06 Al	315	600
BG42	1.15	0.50	0.30	14.5	...	4.00	1.20	...	370	700

(a) Maximum service temperature, based on a minimum hot hardness of 58 HRC

- An important application of the high-temperature bearing steels is aircraft and stationary turbine engines.

- Bearings made from M50 steel have been used in engine applications for many years. Jet engine speeds are being continually increased in order to improve performance and efficiency; therefore, the bearing materials used in these engines must have increased section toughness to withstand the stresses that result from higher centrifugal forces.

- For this reason, the carburizing high-temperature bearing steels, such as M50-NiL and CBS-1000M, are receiving much attention. The core toughness of these steels is more than twice that of the through-hardening steels.

5. AEROSPACE COMPONENT:

- The evolution of the aircraft gas turbine engine depended on the development of materials that could withstand the high operating temperatures and stresses encountered and exhibit outstanding oxidation resistance.

- The differing requirements in specific parts of the engine and the different operating conditions of the various types of gas turbine have led to the development of a wide range of nickel base superalloys with individual balance of high temperature creep resistance, Corrosion resistance, yield strength and fracture toughness.

GAS TURBINE ENGINE:

- New engine designs for commercial airplanes and military fighter jets introduce new requirements for thrust and performance. The fact is that the hotter the combustion in engine the more powerful and efficient the engine becomes.

- Advances such as new **superalloys**, **improved cooling flow designs**, and **thermal barrier coatings** were developed to stretch the capabilities of these components and to take advantage of the thrust and efficiency gains associated with increased combustion temperature.

- The major engine subsystem consist of the fan, the high-pressure compressor (HPC), the combustor, the high- and low-pressure turbines (HPT and LPT), and the exhaust nozzle.

- The engine design contains one non-rotating system and two concentric rotating systems. The non-rotating (stator) system is made up of structural frames and casing. The low pressure rotating system consists of the fan disk(s) and fan blades, the LPT disks and turbine blades, and a connecting shaft. The high pressure rotating system consists of HPC disks/spools and compressor blades, the HPT disks and turbine blades, and a connecting shaft.

- Temperature may vary from subzero to above 1095^{o}C and rotational speeds may climb to more than 15,000rev/min. components may also be subjected to ingested particle impacts.

- The wide variety of operating conditions means that a wide variety of materials must be used to meet the design needs of the engine.

- Aluminum and titanium alloys, plastic and resin matrix graphite composites are frequently used in the fan and the engine nacelle. The HPC use titanium alloys, nickel base superalloys, such as Inconel 718 and steels, such as M152, 17-4PH, and A286.

- The combustor requires heat resistant nickel or cobalt alloys, such as Hastelloy X or Haynes 188, and stainless steels for fuel tubing.

- The turbine section rely on cobalt and nickel superalloys, such as Inconel X750, MAR-M509, Rene 77, Rene 80, Rene 125, and advance directional solidified and single crystal alloys.

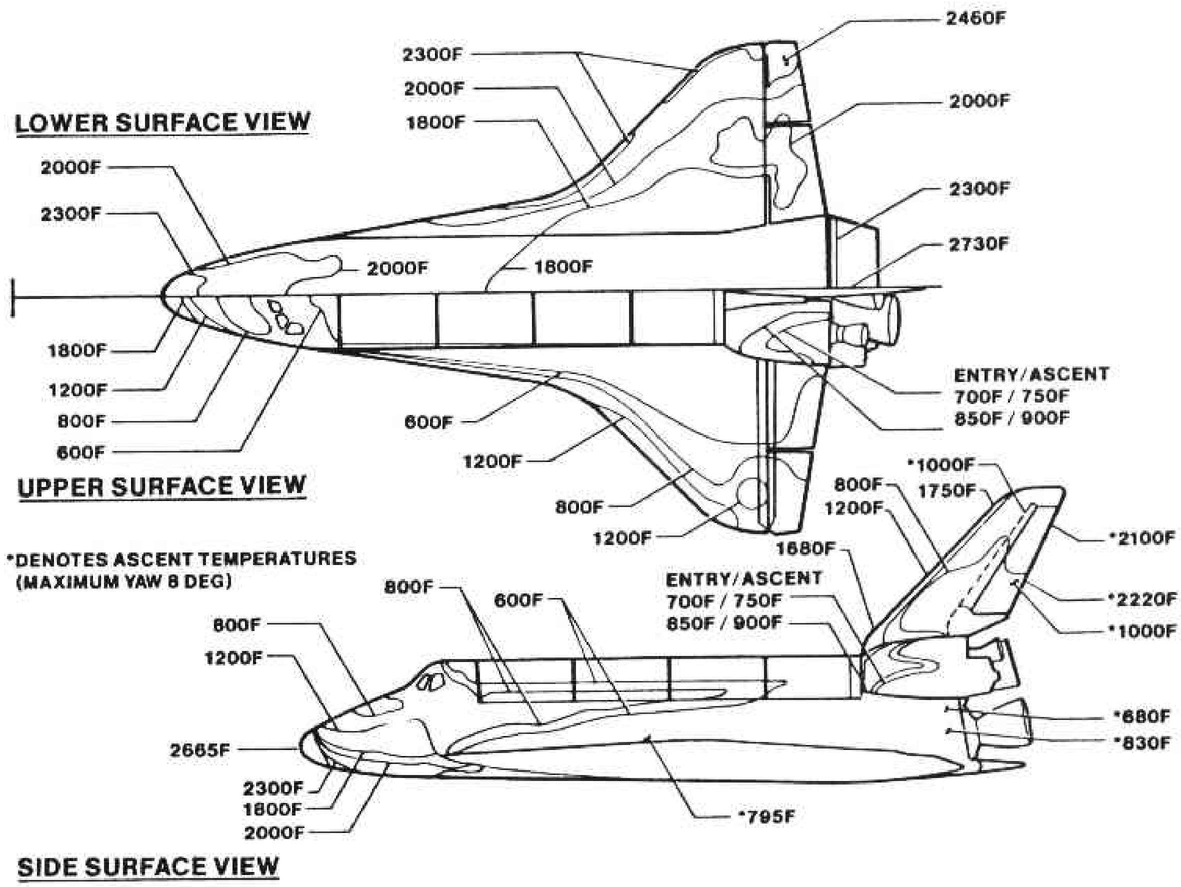
THERMAL PROTECTION SYSTEM:

- The key element of the TPS is the thousands of ceramic tiles that protect the shuttle during reentry. Fig. 1 shows the orbiter and the temperatures reached during reentry in a typical trajectory.

- During reentry of the shuttle into the earth's atmosphere, its surface reaches 1260^{o}C where the ceramic tiles are used.

- Even hotter regions (up to 1650^{o}C) occur at the nose tip and the wing leading edges, where reinforced carbon-carbon (RCC) composite must be employed.

- Fig. 2 indicates the materials chosen for various areas of the TPS.



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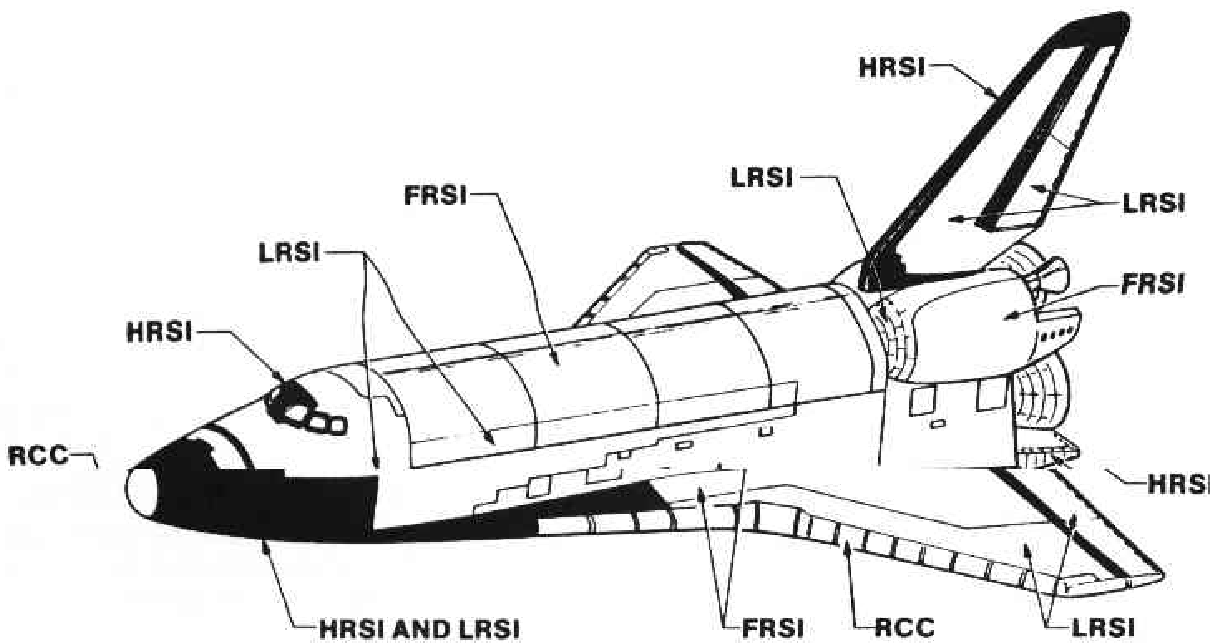
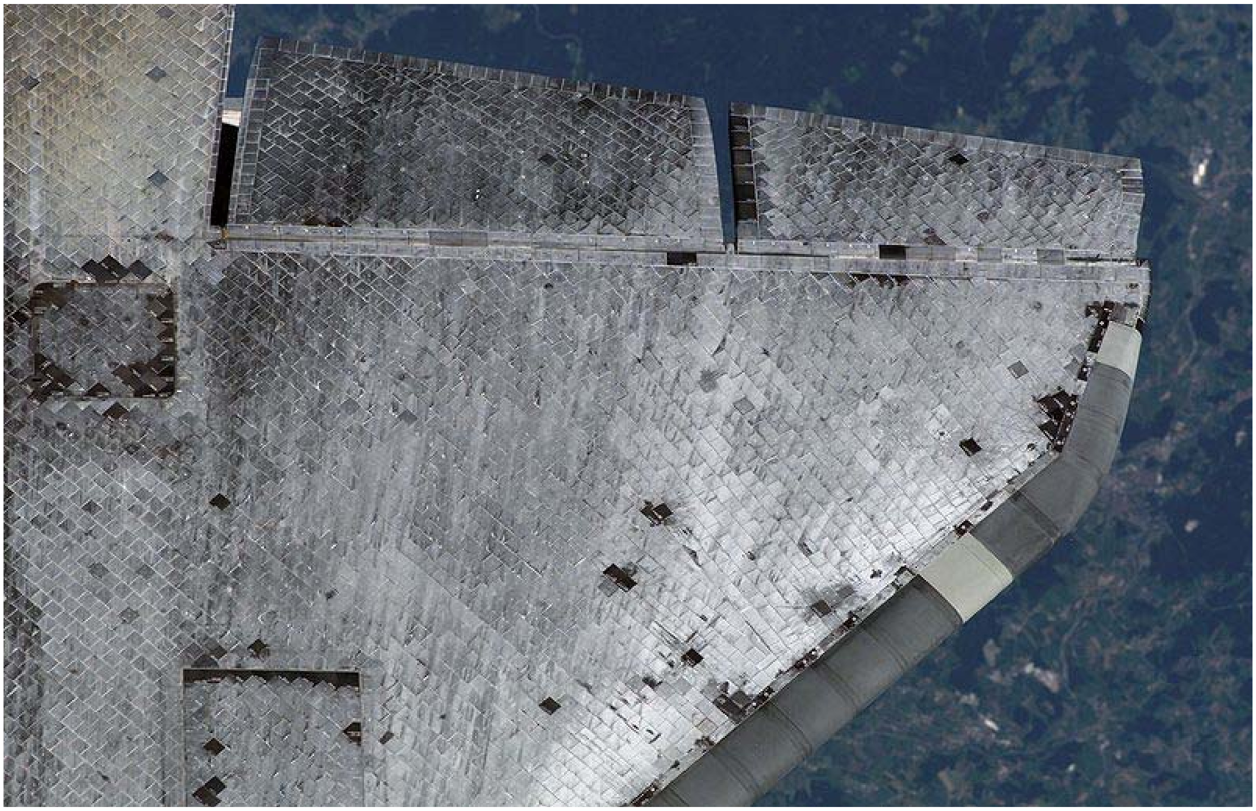
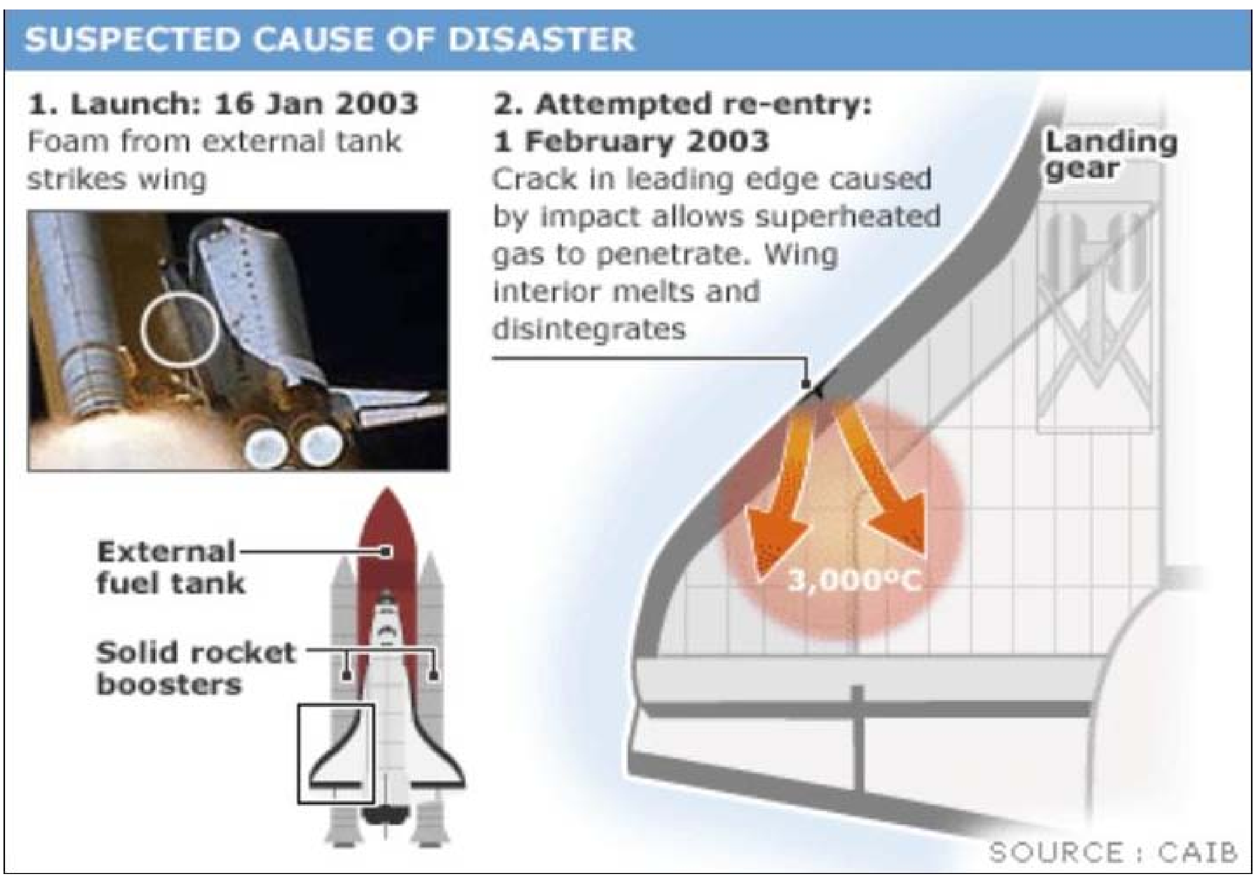


Material generic name	Material temperature capability, °C (°F)(a)	Material composition	Areas of orbiter
Reinforced carbon-carbon (RCC)	to 1650 (3000)	Pyrolized carbon-carbon, coated with SiC	Nose cone, wing leading edges, forward external tank separation panel
High-temperature reusable surface insulation (HRSI)	650–1260 (1200–2300)	SiO_2 tiles, borosilicate glass coating with SiB_4 added	Lower surfaces and sides, tail leading and trailing edges, tiles behind RCC
Low-temperature reusable surface insulation (LRSI)	400–650 (750–1200)	SiO_2 tiles, borosilicate glass coating	Upper wing surfaces, tail surfaces, upper vehicle sides, OMS(b) pods
Felt reusable surface insulation (FRSI)	to 400 (750)	Nylon felt, silicone rubber coating	Wing upper surface, upper sides, cargo bay doors, sides of OMS(b) pods

(a) 100 missions; higher temperatures are acceptable for a single mission. (b) Orbital maneuvering system (OMS) engines

Fig. 2 Thermal Protection System Materials for the Space Shuttle




SUSPECTED CAUSE OF DISASTER
1. Launch: 16 Jan 2003
Foam from external tank strikes wing
2. Attempted re-entry: 1 February 2003
Crack in leading edge caused by impact allows superheated gas to penetrate. Wing interior melts and disintegrates
Landing gear
3,000°C
External fuel tank
Solid rocket boosters
SOURCE : CAIB