NICKEL CHROMIUM ALLOYS

- Two distinct groups of nickel chromium alloys for high temperature uses are as follow.

  - The first group, which includes cast alloys containing ***40 to 50% Ni and 50 to 60% Cr***, are used for heat-resistant and elevated temperature corrosion applications such as structural members, containers, supports, hangers, spacers, and the like in corrosive environments up to 1090^{o}C.

  - The second group, which includes wrought alloys containing ***70 to 80% Ni and 20 to 30% Cr,*** are used as resistance heating elements for oxidizing (air) atmospheres up to 1150^{o}C.

Nickel-Chromium Alloys to Resist Fuel Oil Ash Corrosion

- A growing problem over the past 35 years has been corrosion of heat resistant metals and refractories by the ash from combustion of heavy residual fuel oils used in various industrial furnaces.

- Vanadium Pentoxide (V_2O_5) and alkali metal sulfates are the primary ash constituents responsible for oil ash corrosion. Vanadium exists in certain crude oils as an oil soluble porphyrin complex in variable quantities.

- Various mechanisms have been advanced to explain oil ash corrosion. The simplest explanation is that low melting constituents formed from vanadium Pentoxide and alkali metal sulfates, when molten, exert a fluxing action on the protective oxide films of heat resistant alloys, allowing corrosion to progress in an accelerated manner at temperature ranging from 500-700^{o}C.

- Although a number of methods have been used or proposed to mitigate oil ash corrosion, it is best controlled by proper alloys selection. The 50/50 type nickel-chromium alloys are well established materials for resisting oil ash corrosion.

- At temperature ranging from 900 to 1090^{o}C, the higher chromium alloy is recommended. However, due to its superior as cast ductility, machinability, and weldability, the 50Ni-50Cr alloy is used in the majority of applications in power plants, oil refinery heaters, and marine boiler involving temperatures less than about 900^{o}C. The 50/50 type alloy has better foundry characteristics and lower cost.

- **A high strength nickel chromium alloy**, commonly referred to as IN-657, has been developed that provides the same good resistance to fuel oil ash corrosion exhibited by the standard 50Ni-50Cr alloys, but with improved creep and stress rupture properties.

- This was achieved by modifying the standard alloy with a controlled addition of niobium and reducing the upper permissible limits of nitrogen and silicon as specified in ASTM A560.

Composition wt%												
Grade	C	Mn	Si	S	P	N	Fe	Ti	Al	Nb	Cr	Ni
50Ni-50Cr	0.10	0.30	1.00	0.02	0.02	0.30	1.00	0.50	0.25	-	48-52	Bal
40Ni-60Cr	0.10	0.30	1.00	0.02	0.02	0.30	1.0	0.50	0.25	-	58-62	Bal
50Ni-50Cr-Nb	0.10	0.30	0.50	0.02	0.02	0.16	1.00	0.50	0.25	1.4-1.7	47-52	Bal

Chemical Composition requirements for Nickel-Chromium alloys described in ASTM A560

- The elevated temperature strength of IN-657 is better than that of the standard 50Ni-50Cr alloy, as illustrated by the mean stress rupture relationships shown in fig 1(a).

- Similar comparisons between IN-657 and cast 25Cr-20Ni steel (HK-40), shows their stress rupture strengths to be roughly equal fig 1(b).

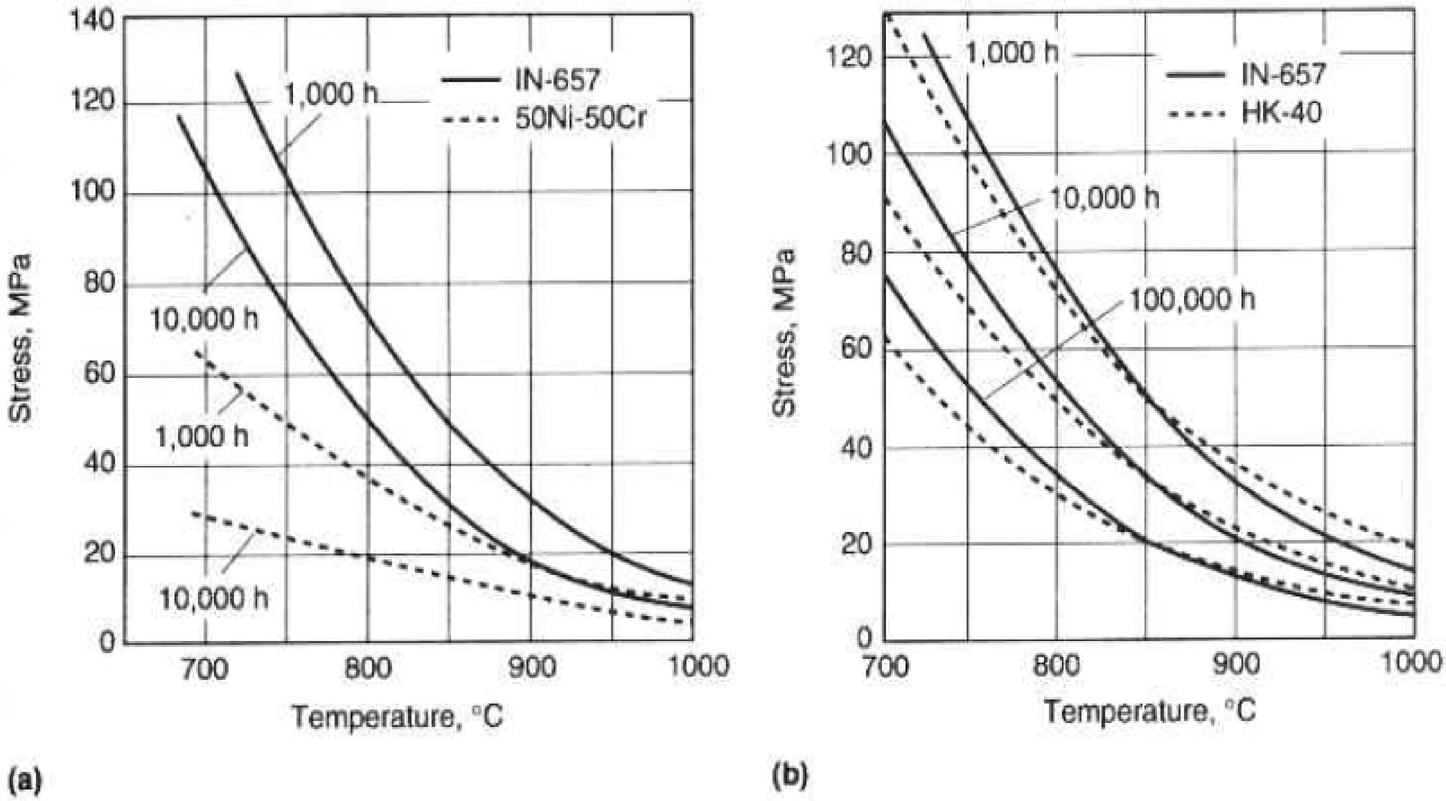


Fig. 1 Stress rupture properties for Nickel Chromium and steel castings derived from Larson Miller Curve (a) IN-657 vs. 50Ni-50Cr. (b) IN-657 vs. HK-40

- The stress rupture ductility values of IN-657 are generally equal or superior to those of 50Ni-50Cr alloy and 25Cr-20Ni steel, depending on the test temperature.

- In common with most cast heat resistant alloys, including the standard 50Ni-50Cr type, IN-657 suffers a loss of room temperature tensile ductility after service at high temperatures.

- However, the niobium containing nickel chromium alloys show less impairment of ductility than the standard 50Ni-50Cr alloy.

- Fig 2 compares IN-657, 50Ni-50Cr, and 25Cr-20Ni (HK-40) steel for resistance to oil ash corrosion. The weight losses shown were determined after half immersion tests in 80% V_2O_5 + 20% Na_2SO_4. The results recorded for HK-40 relate to only 16h of exposure, compared with 300h for the other two alloys.

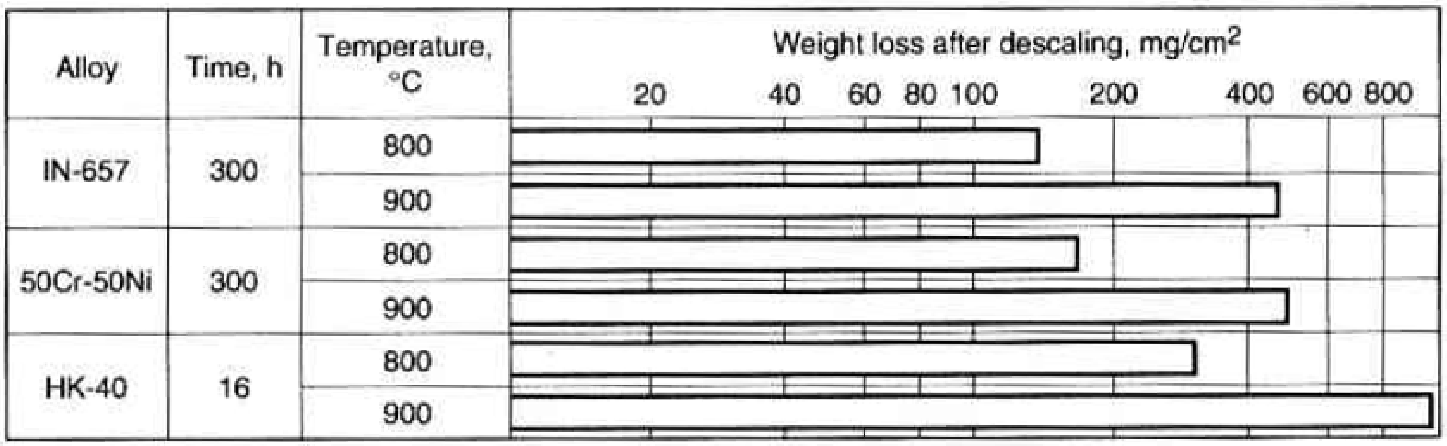


Fig. 2 comparison of fuel oil ash corrosion resistance for nickel-chromium alloys and HK-40 steel

Nickel-Chromium Alloys for Resistance Heating Elements

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

- The primary requirements of materials used for heating elements are

1. *High melting point*
2. *High electrical resistivity*
3. *Reproducible temperature coefficient of resistance*
4. *Good oxidation resistance*
5. *Absence of volatile components and*
6. *Resistance to contamination.*

- Other desirable properties are

7. *Good elevated temperature creep strength*
8. *High emissivity*
9. *Low thermal expansion, and low modulus (both of which help minimize thermal fatigue)*
10. *Good resistance to thermal shock and*
11. *Good strength and ductility of fabrication temperatures.*

- Materials used for resistance heating application include:

  - *Nickel-chromium alloys (80Ni-20Cr and 70Ni-30Cr)*
  - *Iron-nickel-chromium alloys*
  - *Iron-chromium-aluminum alloys*
  - *Pure metals (e.g., platinum, molybdenum and tungsten)*
  - *Nonmetallic materials (e.g., silicon carbide and graphite)*

- Of these five material groups, nickel-chromium ad iron-nickel-chromium alloys are the most widely used heating materials in electric heat treating furnace.

- The 80Ni-20Cr alloys permit a wider range of operating temperatures because they have the greatest resistance to oxidation, and therefore hey can be used at higher temperatures than other nickel-chromium and iron-nickel-chromium alloys.

- Small silicon additions (0.75 to 1.75%) can also improve oxidation resistance. They re not recommended for use in sulfur-bearing and reducing atmospheres at high temperature.

- In general, nickel-chromium heating elements are unsuitable above 1150°C because the oxidation rate in air is too great and the operating temperature is too close to the melting point of the alloy (the approximate melting point of 80Ni-20Cr is 1400°C). As shown in fig. 3, the strength of 80Ni-20Cr drops significantly when temperature exceeds 650°C.

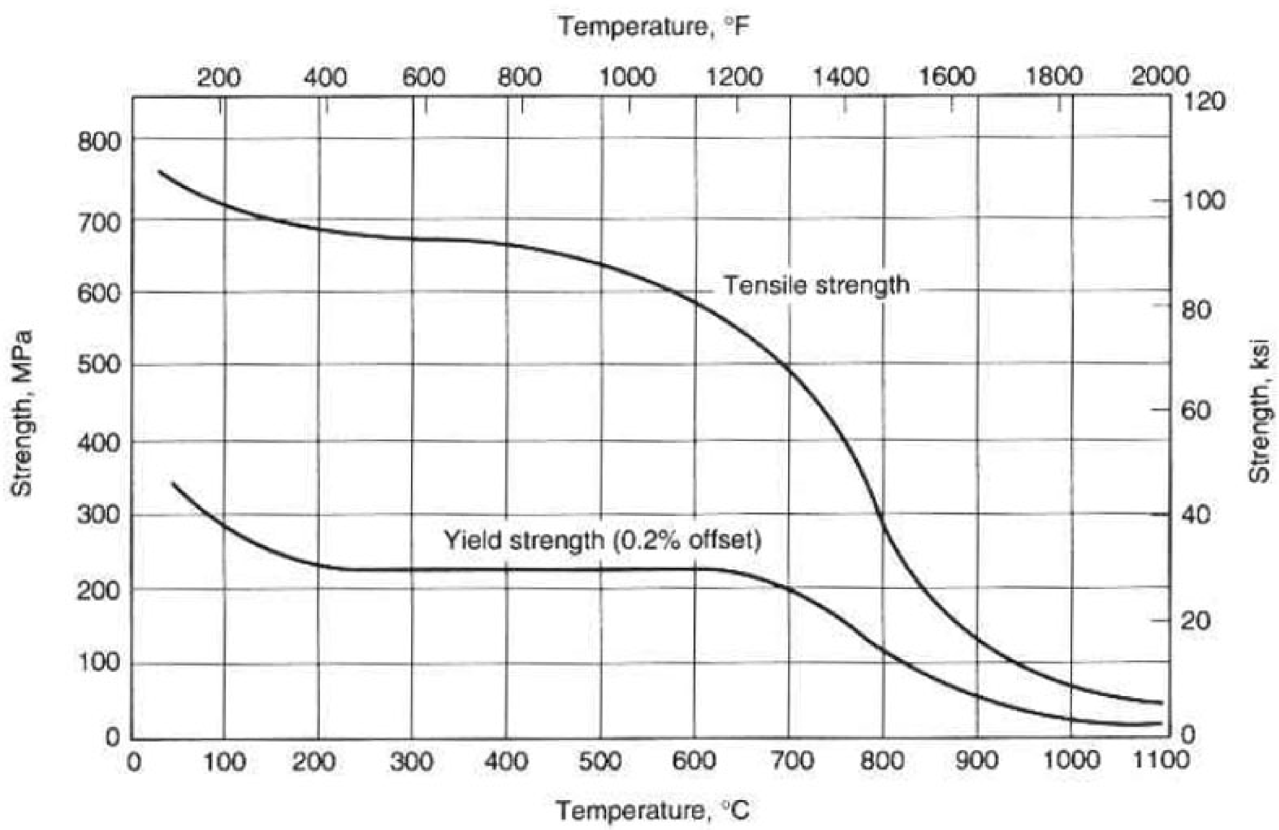
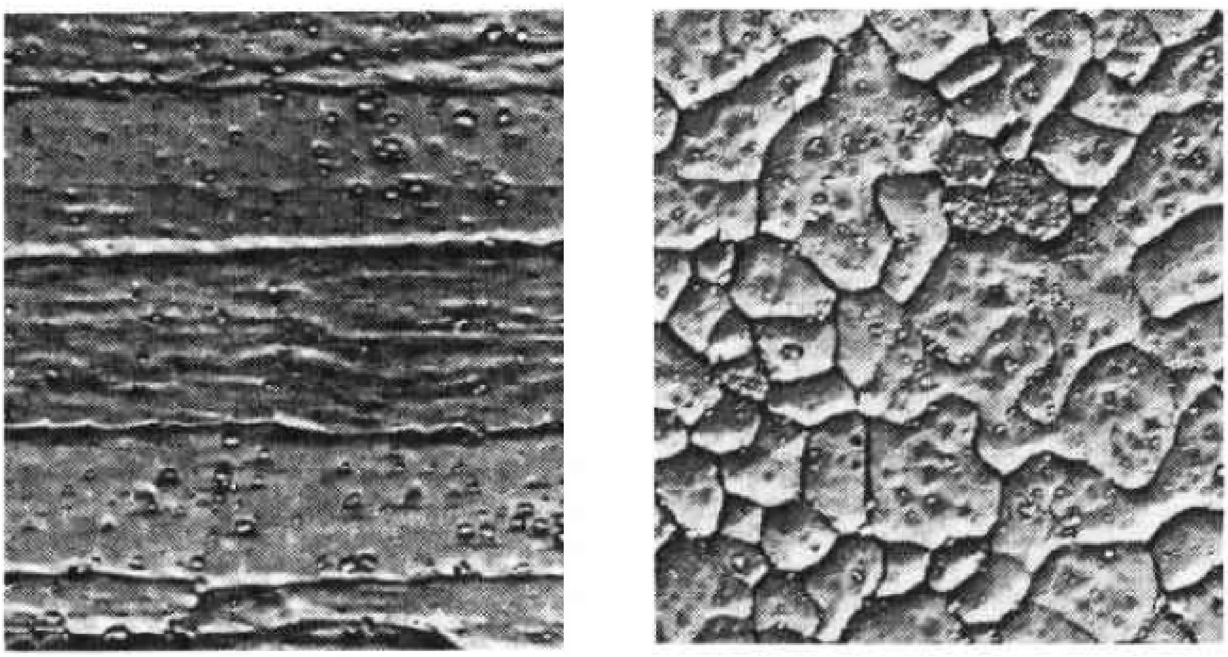


Fig. 3 Effect of temperature on the tensile properties of an annealed 80Ni-20Cr resistance heating element alloy

Nickel-Thoria Alloys

- The Thoria- dispersed nickel alloys (TD Nickel) contain thorium oxide additions (~2 wt %) for increased elevated temperature strength up to 1200°C.

- Dispersion strengthened nickel was one of the first commercially available dispersion strengthened materials. In these powder metallurgy alloys, either or nickel or a 78Ni-20Cr alloy is mixed with a fine dispersoid of Thoria (ThO_2). Thoria contents range from 1.80 to 2.60% ThO_2, with the normal content being 2.0% ThO_2. A typical microstructure is shown in fig. 4.



(a) (b)

Fig. 4 Replica electron micrograph of annealed TD Nickel sheet, showing grain structure and dispersion of ThO_2. (a) Longitudinal (rolling) direction. (b) Transverse section. Both at 7000X

- Commonly referred to as TD Nickel or TD NiCr, these alloys were developed for use in components in combustion systems of advanced gas turbine engines, fixtures for high-temperature tensile testing, and specialized furnace components and heating elements.

- Elevated temperature tensile properties and stress rupture characteristics are given in Fig. 5; TD Nickel demonstrates superior stress rupture properties at very high temperatures (850 to 1200°C).

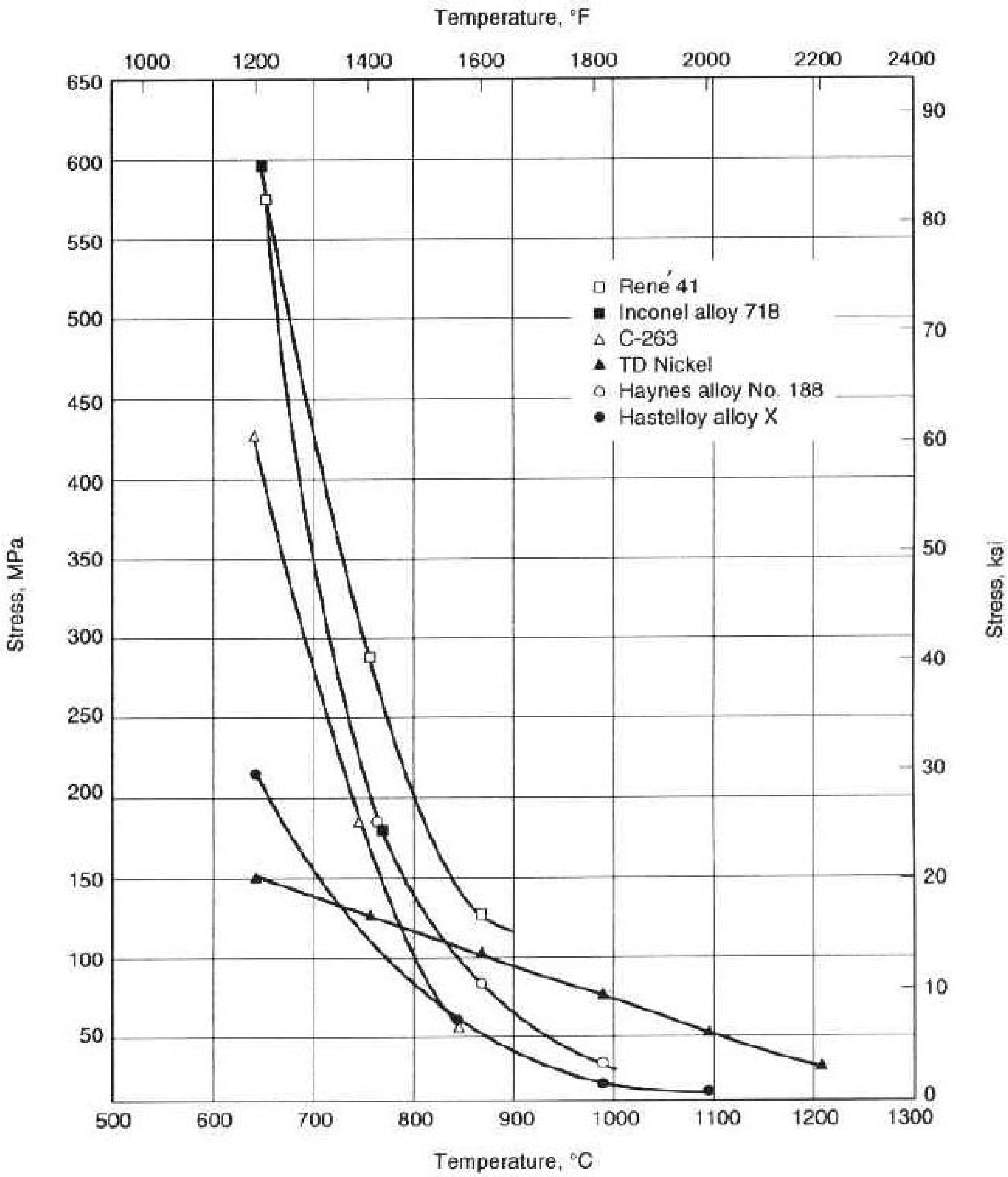


Fig. 5 The 1000 h stress-rupture strength of TD Nickel and other heat resistant alloys

- There are several disadvantages associated with TD Nickel that have limited its commercial viability.

    - This material has poor oxidation resistance and should be coated for long term high temperature surface stability.
    - It is difficult to process and cannot be hot worked, and
    - It is mildly radioactive (thorium is an actinide metal).

- As a result of the problems, production of TD Nickel has ceased. Today yttria (Y_2O_3) dispersion strengthened nickel-base superalloys are being used for elevated temperature applications.