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Recent Developments in Metastable β Strip Alloys

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The strip producibility, good fabricability, and excellent mechanical properties of β alloys make them useful for a variety of fabricated sheet metal structures on aircraft. TIMETAL 15-3 is currently used for environmental control system ducting on the Boeing 777 and, more recently, has been used on the Airbus A380. For applications that require exposure to higher temperatures, such as the exhaust assemblies, TIMETAL 21S is now used on the Boeing 777, Airbus A340, and various other civil and military aircraft.

Keywords Beta 21S, Ti-15Mo-3Nb-3Al-0.2Si, Ti-15V-3Sn-3Cr-3Al

1. Introduction

This article will summarize the recent developments in the manufacturing of TIMETAL 15-3 and TIMETAL 21S strip products in general terms. Updated information on structure and properties are presented for each alloy, along with some discussion of recent issues. Finally, successful applications on current commercial aircraft are described.

2. Manufacturing Considerations

2.1 Processing

Although the alloy development for TIMETAL 15-3 and 21S was completed in the 1970s and 1980s (respectively), full-scale production was not realized until the 1990s with the advent of the widespread usage of β alloys on the Boeing 777 (Ref 1). The relatively slow implementation can be attributed to the time taken to understand the critical factors relating to manufacturing. The nominal processing route for the production of β strip alloys at TIMET is summarized in Fig. 1.

2.2 Melting

TIMETAL 21S is currently produced by multiple vacuum-arc-remelting (VAR). An option for cost savings is the implementation of potentially more efficient melting and conversion routes. A promising technology is the melting of ingots as electron-beam single-melt (EBSM) slabs, which can provide dimensional advantages as well as opportunities to recycle various forms of scrap. The rectangular cross section of as-cast slabs is an efficient shape for subsequent hot-rolling. Initial EBSM trials have been promising, and development is ongoing (Ref 2).

2.3 Annealing

Annealing is a critical factor impacting both fabrication and final aging response. The annealing practice must be optimized to produce the correct microstructure. The importance of microstructure on fabrication performance will be discussed in more detail later. The continuous vacuum anneal process of TIMET provides a tool that is used to control the microstructure and to reduce hydrogen content while preventing excessive surface contamination.

2.4 Flatness

For effective fabrication, the strip product must be flat. Beta alloys have a low elastic modulus and high yield strength. This means that the shape defects such as crossbow, oil canning, and center buckle, which occur in all coil products, are difficult to correct especially at thin gages. Substantial improvements have been implemented in recent years. However, the increased use of robotic fabrication methods places ever-tighter requirements on flatness, and, thus, efforts to avoid and correct these shape defects are ongoing.

3. TIMETAL 21S Strip Properties and Microstructures

The general properties of TIMETAL 21S have been previously summarized elsewhere (Ref 3, 4). This article will discuss more recent issues with regard to heat treatment, microstructure, and mechanical properties.

The two most common aging cycles for TIMETAL 21S are: (a) 593 °C (1100 °F) for 8 h and (b) 691 °C (1275 °F) for 8 h plus 649 °C (1200 °F) for 8 h.

The 1100 °F (593 °C) age is used for parts used at moderate temperatures that require high strength. The 1275 + 1200 °F (691 + 649 °C) age is used for parts requiring maximum thermal stability. The usage of any particular condition depends, of course, on the specific temperatures, stresses, and expected service life. Mechanical properties for each condition are summarized in Table 1 (Ref 5). Note that some users specify other aging cycles for their own particular applications. Representa-

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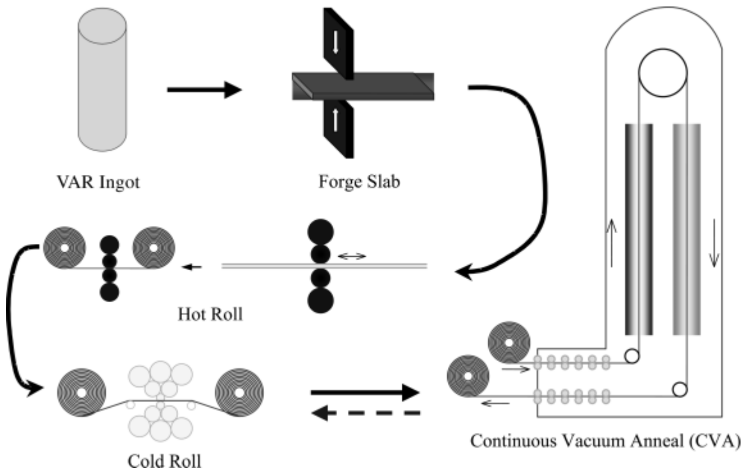


Fig. 1 Outline of typical manufacturing steps for TIMET aerostrip production

Table 1 Typical mechanical properties of TIMETAL 21S strip and sheet (Ref 15)

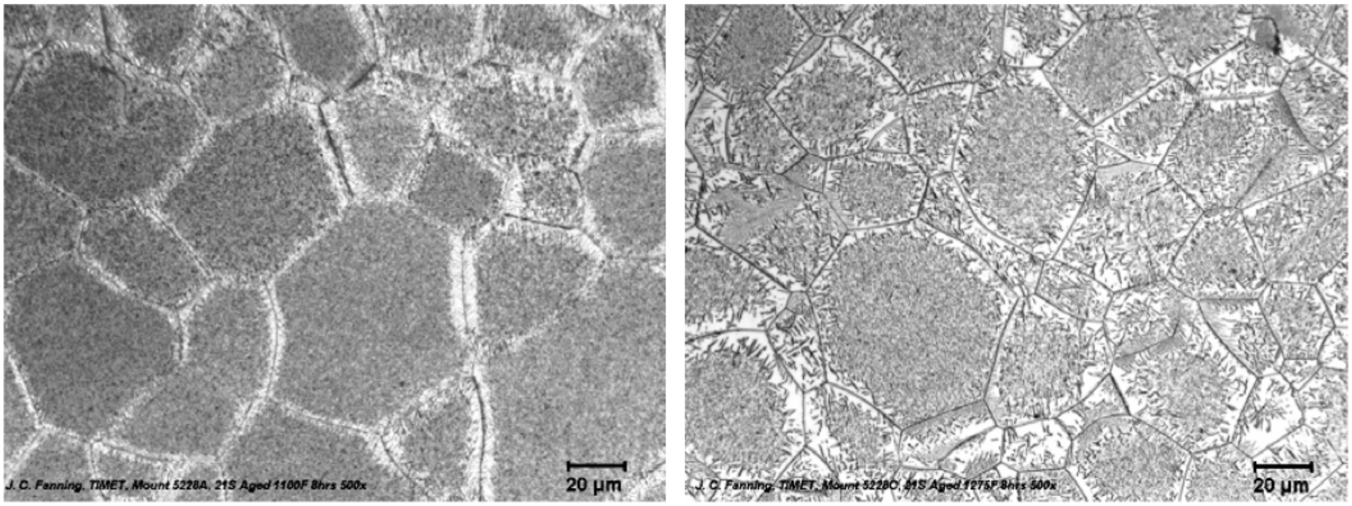
	Strip and sheet(a)					
	1100 °F (593 °C) for 8 h			1275 °F (690 °C) for 8 h + 1200 °F (649 °C) for 8 h		
		Average			Average	
Mechanical properties	**No./lots(b)**	**ksi**	**MPa**	**No./lots(b)**	**ksi**	**MPa**
UTS						
L	99/6	169.2	1166	78/12	141.4	975
LT	116/10	170.3	1174	65/11	144.4	995
TYS						
L	99/6	156.0	1076	77/12	130.8	902
LT	116/10	158.1	1090	64/11	136.2	939
CYS						
L	21/7	160.8	1108	23/7	140.6	969
LT	13/5	171.2	1180	14/5	148.1	1021
SUS						
L	24/8	113.1	780	24/7	101.2	698
LT	15/5	114.8	791	15/5	100.2	691
BUS						
L (e/D = 1.5)	15/5	267.2	1842	14/5	241.3	1664
LT (e/D = 1.5)	15/5	266.0	1834	15/5	239.9	1654
L (e/D = 2.0)	24/8	330.3	2278	23/7	296.1	2042
LT (e/D = 2.0)	15/5	328.9	2268	14/5	298	2054
BYS						
L (e/D = 1.5)	12/5	242.0	1668	12/5	201.8	1391
LT (e/D = 1.5)	11/5	247.6	1707	15/5	201.9	1392
L (e/D = 2.0)	21/8	272.1	1876	23/7	236.5	1630
LT (e/D = 2.0)	14/5	284.1	1959	13/5	245.9	1696
E, 10^3						
L	19/5	16.0	109	56/12	15.5	107
LT	27/6	16.0	113	43/11	16.4	113
E_c, 10^3						
L	12/4	16.5	117	14/5	15.3	106
LT	13/5	17.0	117	14/5	16	111
Tensile elongation						
L	99/6	11.0%		78/12	14.1%	
LT	116/10	10.0%		65/11	13.5%	

Note: UTS, ultimate tensile strength; TYS, tensile yield strength; CYS, compressive yield strength; SUS, shear ultimate strength; BUS, bearing ultimate strength; BYS, bearing yield strength; E, 10^3, tensile elastic modulus; E_c, 10^3, compressive elastic modulus. (a) 0.016-0.125 in. (0.4-3.2 mm); (b) No. represents the number of data points, *lots* represents the number of lots.

tive photomicrographs of high- and low-temperature age cycles are shown in Fig. 2.

An interesting characteristic of TIMETAL 21S is that the actual service performance has been better than might have been predicted from coupon testing alone. The acoustic fatigue environment (typically consisting of very high frequency, medium to high temperatures, and low stresses) is very difficult to characterize. Therefore, the system performance is typically verified by actual component testing.

TIMETAL 21S has very high creep strength for a β alloy, but its creep strength is still relatively low in comparison to near-α creep-resistant alloys (6242, 834). Although near-α alloys have better creep properties (Ref 6), the lack of cold formability inhibits their practical use in many types of



(a)

(b)

Fig. 2 Photomicrograph of TIMETAL 21S strip after aging at 593 °C (1100 °F) (a) and 691 °C (1275 °F) (b). The relative coarseness of the α, which dictates the strength and ductility levels, is readily visible.

structures. Thus, TIMETAL 21S offers a practical compromise.

4. TIMETAL 15-3 Strip Properties and Microstructures

The general properties of TIMETAL 15-3 have been previously summarized elsewhere (Ref 7, 8). Mechanical property trends for TIMETAL 15-3 strip, based on several years of production data, are summarized in Fig. 3 (Ref 9).

The fabrication performance is closely related to the degree of recrystallization that is present after solution treatment. Recrystallization is a function of chemistry, prior processing, and final annealing conditions. The importance of chemistry was illustrated as the titanium industry switched from older titanium sponge production technologies to the current vacuum-distilled sponge technology. Changes in certain low-level residual impurities in the sponge were found to impact the recrystallization behavior of TIMETAL 15-3 in particular. The recrystallization of TIMETAL 15-3 (and all of the other metastable β alloys) follows a classic nucleation and growth process that depends on the strain energy (especially cold work) and the annealing cycle used. However, the actual response of the material to a given thermomechanical processing cycle is, in turn, strongly influenced by the presence of certain trace elements in the material. These elements retard the motion of dislocations and grain boundaries, and thus inhibit the nucleation and growth of new grains during recrystallization. As changes were made to the sponge sources, adjustments had to be made to the processing and heat-treatment practices to maintain the optimum level of recrystallization. Since the early 1990s, several incremental process changes have been implemented to optimize the degree of recrystallization and to improve consistency.

Recrystallization also has an impact on the aging kinetics. Highly recrystallized microstructures, although ideal for cold formability, have fewer heterogeneous nucleation sites for α within β grains. In some circumstances, this can result in an inadequate aging response. This is illustrated in Fig. 4. Note that lower-temperature aging cycles are less affected than higher-temperature aging cycles. There is also a significant

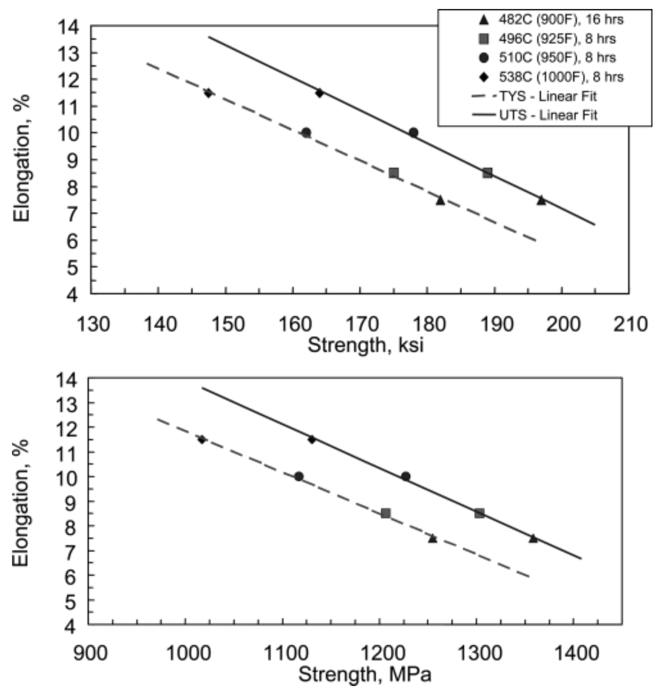


Fig. 3 Strength versus ductility for TIMETAL 15-3 strip. Each datum point for each aging cycle represents the average longitudinal and transverse values for production data (Ref 9).

effect of heat-up rate. The inherently slow heat-up rate (such as in a vacuum furnace) used during the manufacture of parts typically results in an acceptably aged structure.

5. Applications

The early promise of cold-formable β alloys as a panacea for all fabricated titanium sheet metal structures has not been fully realized. Nevertheless, there are several applications in which the attributes of cold-formable β alloys have proven to be useful in modern aerostructures.

As shown in Fig. 5 and 6, TIMETAL 15-3 strip is now used

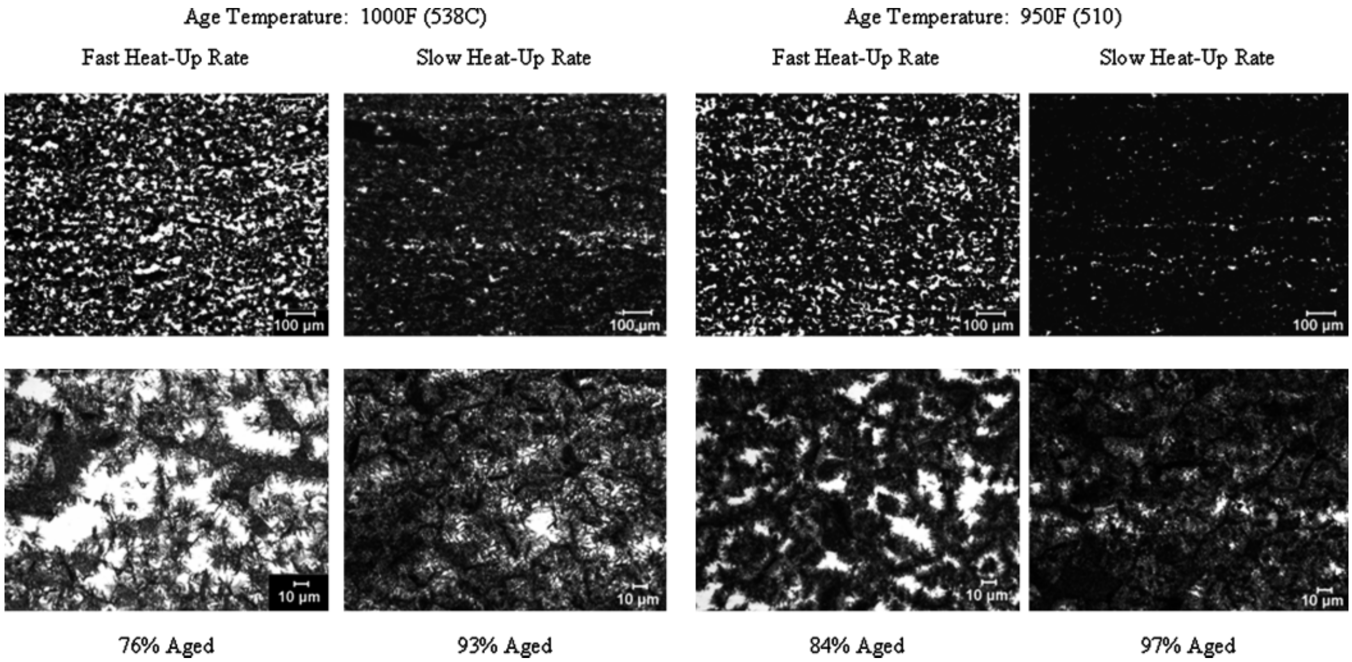


Fig. 4 Transverse photomicrographs of 2 mm (0.080 in.) *TIMETAL* 15-3 strip aging at 8 h at noted temperature (1000 F [538 °C] of 950 F [510 °C] using a fast or slow heat-up rate to the aging temperature. Top row shows overall microstructure at low magnification. Bottom row shows morphology of alpha precipitates at high magnification. Degree of aging was measured at lower magnifications than those shown.

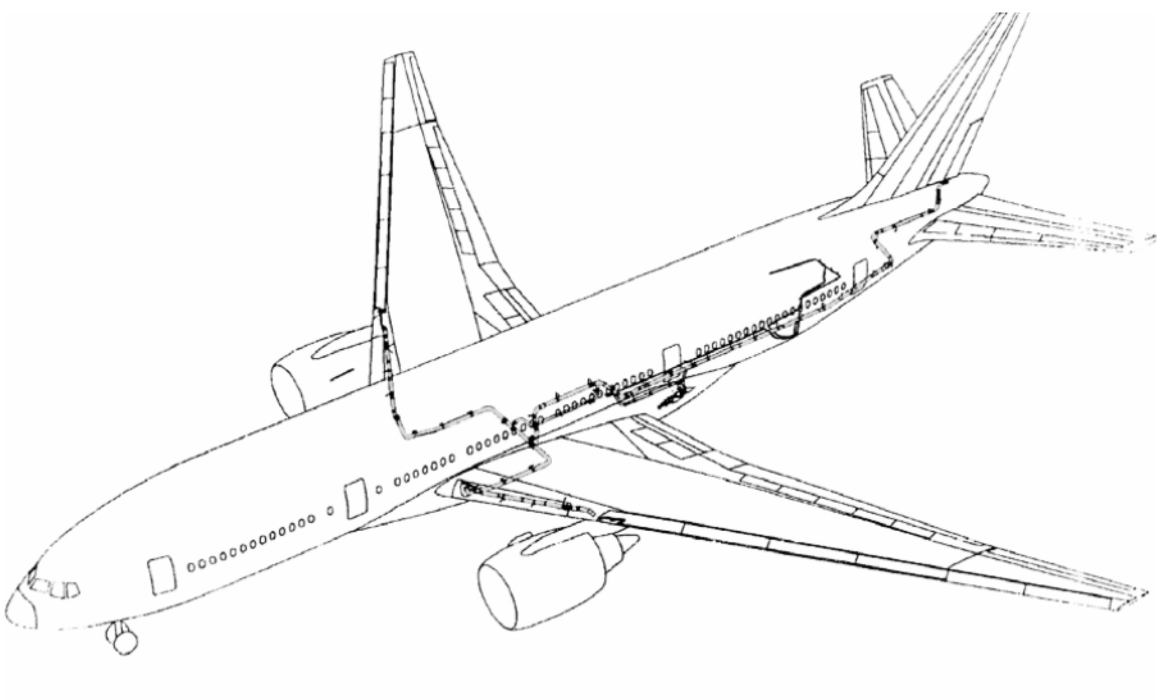


Fig. 5 Schematic diagram of TIMETAL 15-3 pneumatic environmental control system on the Boeing 777 (Ref 10)

in the environmental control system ducting of several aircraft models, including the Boeing 777 and Airbus A380. TIMETAL 15-3 ducting has been used in the Boeing 777 since 1992 (Ref 1). Using TIMETAL 15-3 instead of commercially pure titanium saves approximately 64 kg (140 lb) per Boeing 777 aircraft (Ref 10). Tubing wall thicknesses are typically 0.5 mm (0.020 in.) or 0.8 mm (0.032 in.). The ducts carry air at temperatures of up to 232 °C (450 °F) (Ref 1). More recently, TIMETAL 15-3 has been considered for use in portions of the ducting system of the Airbus A380 (Fig. 6) (Ref 11).

For plug-and-nozzle and other types of exhaust systems, TIMETAL 21S is now used in lieu of much heavier nickel alloy systems on several aircraft models. Examples for the Boeing and Airbus aircraft are provided in Fig. 7 and 8, respectively. Using TIMETAL 21S instead of nickel-base alloys saves approximately 82 kg (180 lb) on each Rolls Royce Trent engine (or 164 kg [360 lb] total) on the Boeing 777 aircraft (Ref 3). TIMETAL 21S is also used in the exhaust systems of several military aircraft programs.

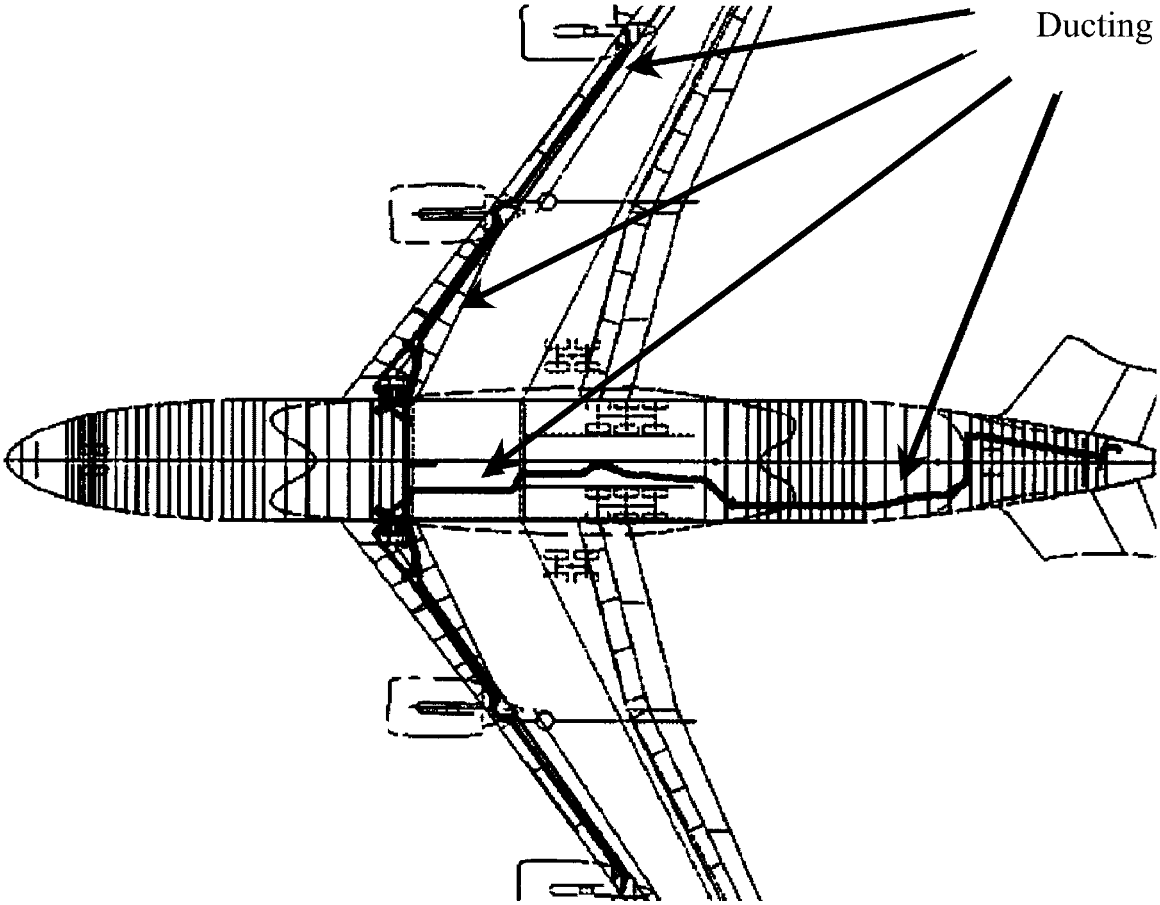


Fig. 6 Schematic diagram of TIMETAL 15-3 bleed air system on the Airbus A380 (Ref 11)

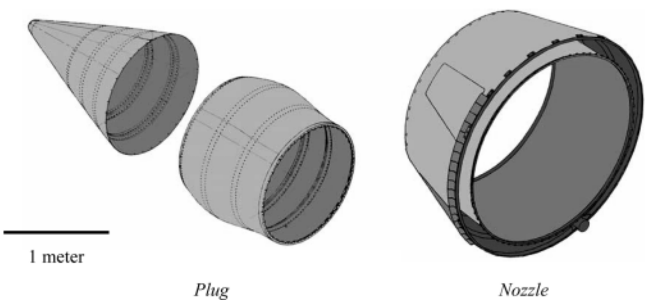


Fig. 7 Schematic diagram of TIMETAL 21S plug-and-nozzle assemblies for the Trent 800 engine on the Boeing 777 (Ref 10)

Fig. 8 TIMETAL 21S plug-and-nozzle assemblies (arrows) for the Trent 500 engine on the A340-500/600. The photograph is courtesy of Aeronca, Inc. (2000).

6. Summary

In the past decade, β strip alloys have proven useful in several aircraft applications, including TIMETAL 15-3 for pneumatic ducting and TIMETAL 21S for engine exhaust systems.

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