Stabilisation Treatment of Titanium Alloy VT9

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ABSTRACT

Systematic investigations of tensile properties of $\alpha + \beta$ type high temperature *Ti* alloy VT9 (*Ti*-6 *Al*-3.3 *Mo*-1.65 *Zr*-0.3 *Si* wt. per cent) developed on ageing at 803, 823 and 853 K for 2, 6 and 12 hr, respectively following the solution treatment in $\alpha + \beta$ phase field at 1233 K for 1 hr and air cooling, show that the highest tensile strength values are obtained on ageing at 823 K for 6 or 12 hr. In view of the shorter duration of ageing, the ageing treatment at 823 K for 6 hr is considered appropriate stabilisation treatment for this alloy. The tensile strength values of the alloy VT9 from the newly-established stabilisation treatment are considerably higher than those resulting from the earlier reported stabilisation treatment (at 803 K for 6 hr), in particular at room temperature.

1. INTRODUCTION

High temperature *Ti* alloys like VT9, IMI 685, 829 and 834 are normally subjected to the stabilisation treatment in the range 773-873 K for a few hours, following the solution treatment either in $\alpha + \beta$ or β phase field, for relieving the residual stresses and stabilising the microstructure. Alloy VT9 (Russian designation) is an important $\alpha + \beta$ type alloy, designed for high temperature applications as compressor disc and blade material in jet engines. It develops a wide variety of microstructures controlled by solution treatment and subsequent rate of cooling[1,2]. The β transus temperature of this alloy[1] is ~1243 K. While β

solutionising and quenching in water results in transformation of the β phase to a single-phase microstructure of orthorhombic martensite[3] (α''). Slow cooling on the other hand gives rise to Widmanstatten structure of coarse α laths, and β plates retained between the α laths. The thickness of the α laths and retained β plates depend on the rate of cooling, following the solution treatment. It increases with decrease in rate of cooling. In fact another phase, designated as interface phase with face-centred cubic structure, has been reported to exist in the transformed β phase lying at the interface of the α platelets/laths and the retained β phase, in the alloy[4] VT9 and also in other $\alpha + \beta$ and

near α type *Ti* alloys[5-18]. The interface phase in such alloys was proposed to be an intermediate product in the transformation of β to α[8] phase. However, it was argued that the interface phase[14] was TiH_2 and was characterised as an artifact which develops during electrothinning[15]. Recent investigations, however, have shown that the interface phase in the *Ti* alloy is not an artifact but appears to be a microstructural constitutent and develops under specific heat-treated conditions[19-21]. Heat treatment in the α + β phase field results in a duplex microstructure, consisting of primary α and transformed β phase, when the material is processed in the α + β phase field, prior to heat treatment.

The commercial stabilisation treatment for VT9 is reported as ageing at 803 K for 6 hr, followed by air cooling[2]. Recent studies conducted on the influence of ageing treatment for 24 hr in the range 573-873 K following α + β/β solution treatment and subsequent cooling at different rates, on tensile properties of VT9 at room temperature[22]. It was observed that a good combination of strength and ductility resulted from ageing at 723 K or 823 K; however, deterioration in properties was observed from ageing at 873 K. Since VT9 is designed for high temperature applications (up to ~773 K), there is not much relevance of the stabilisation treatment at temperature < 773 K. Also ageing of VT9 at elevated temperature (873 K and above) gives rise to precipitation of silicides[5]. Hence the stabilisation treatment must be given below 873 K to avoid precipitation of any silicide which are known to have detrimental effect on mechanical properties of such alloys. Further, in the earlier investigation[22], the influence of ageing period on tensile properties was not examined and all the ageing treatments were given for a long and fixed duration of 24 hr.

In view of the above facts relating to the effect of ageing treatments on tensile properties of VT9, the present investigation examines the effect of duration of ageing treatment at different temperatures, within a narrow range (803-853 K), on tensile properties of VT9 at room temperature and 773 K following α + β solution treatment and

air cooling, to establish the most appropriate stabilisation treatment to yield best combination of strength and ductility in VT9.

2. EXPERIMENTAL PROCEDURE

VT9 produced with trade name GTM 900 at MIDHANI, Hyderabad, was procured in the form of rods of 30 mm diameter in mill-annealed condition. It contained by weight per cent 6.5 *Al*-1.75 *Zr*-3.3 *Mo*-0.3 *Si* 12 ppm H_2, 12 ppm N_2, 574 ppm O_2 and balance *Ti*. The rods of 30 mm diameter were longitudinally sectioned into four quadrants and machined to rods of 10 mm diameter. Standard Hounsfield tensile specimens with gauge length and diameter 15.4 mm and 4.5 mm, respectively were machined from these cylindrical blanks and were solution-treated in the α + β phase field at 1233 K for 1 hr under vacuum (10^{-3} torr) and cooled in air. The solution-treated samples were sealed in silica tube under vacuum (10^{-3} torr) and were given ageing treatment for 2, 6 and 12 hr, separately at 803, 823 and 853 K, respectively and cooled in air. Tensile tests were carried out at room temperature as well as at 773 K in air at a nominal strain rate of 5×10^{-4}/s. After testing, the tensile samples were longitudinally sectioned and examined for the microstructural modification, if any, resulting from testing, particularly at the elevated temperatures. The specimens to be tested by optical microscopy were mechanically polished and etched by the etchant containing 10 per cent *HF*, 5 per cent HNO_3 and 85 per cent distilled water by volume.

3. RESULTS

As expected, the optical microstructure of VT9 solution treated in the α + β phase field at 1233 K for 1 hr and cooled in air, showed a duplex microstructure consisting of primary α and transformed β phases. A typical microstructure of the α + β solution-treated air cooled, and stabilised (823 K for 6 hr) specimen is shown in Fig. 1. The optical micrograph shows the primary α (the light-etching phase) distributed in the dark matrix of the transformed β phase. The microstructure of the transformed β phase may be seen to consist of
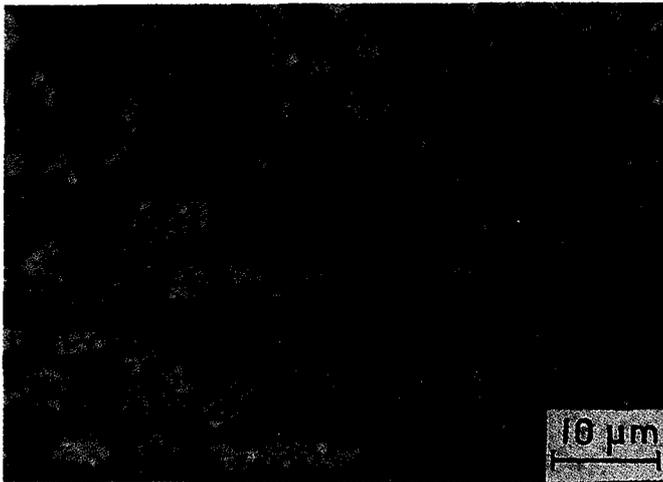
Figure 1. Optical micrograph showing primary α and transformed β microstructure in VT9 in the α + β solution-treated air cooled and stabilised condition (823 K for 6 hr).

platelets of α phase and thin strips of β phase retained between the secondary α platelets. Tensile properties of VT9 at room temperature, following the ageing treatment at 803, 823 and 853 K for varying periods of 2, 6 and 12 hr, respectively are presented in Table 1. These values are average of

Table 1. Tensile properties of VT9 in the α+β solution-treated, air cooled and differently aged conditions at room temperature

Ageing temp. (K)	Ageing time (hr)	σYS (MPa)	σUTS (MPa)	σf (MPa)	εup (%)	εtp (%)	RA (%)
803	0	921	1049	848	7.2	17.5	38
	2	988	1099	882	6.2	17.2	40
	6	978	1108	890	6.5	17.7	41
	12	965	1127	884	6.2	14.6	32
823	0	921	1049	848	7.2	17.5	38
	2	947	1088	862	6.2	17.2	34
	6	1033	1169	973	5.8	16.2	36
	12	1063	1184	813	6.5	15.9	36
	18	1018	1087	933	5.1	13.1	33
	24	975	1090	972	5.1	12.2	32
853	0	921	1049	848	7.2	17.5	38
	2	948	1087	911	6.2	15.3	32
	6	991	1107	954	6.2	15.3	30
	12	1026	1112	968	6.2	15.1	29

two tests. The variations in strength as well as ductility values with the duration of ageing at three different temperatures are shown in Fig. 2. It is obvious from the data in Table 1 and Fig. 2 that there is appreciable effect of ageing treatment on the strength values, i.e. on both the yield strength as well as the ultimate tensile strength (UTS). However, the influence on yield strength is relatively more pronounced than that on UTS. There is less influence of the ageing treatment on the ductility values, in particular, the per cent elongation. It may be seen that both yield strength as well as UTS are the highest for the specimen aged at 823 K for 12 hr, and there is an increase of nearly 9 per cent and 7 per cent in the yield strength and UTS, respectively, in comparison to the respective values for the specimen, stabilised according to the earlier stabilisation treatment (803 K for 6 hr).

The ductility values, however, are nearly comparable for all the ageing treatments. The variation of yield strength and UTS at room temperature with the duration of ageing at 823 K showed continuous increase in both the strength values on ageing up to 12 hr. Ageing treatments were given for longer durations of 18 hr and 24 hr to establish the peak values of these parameters in the

Table 2. Tensile properties of VT9 follwing α+β solution treatment and differently aged conditions at 773 K

Ageing temp. (K)	Ageing time (hr)	σYS (MPa)	σUTS (MPa)	σf (MPa)	σtp (%)
803	0	939	802	528	24.2
	2	639	803	485	25.2
	6	648	812	509	24.1
	12	633	843	511	23.7
823	0	639	802	528	24.2
	2	660	818	509	25.6
	6	657	816	517	23.9
	12	684	824	509	24.8
853	0	639	802	528	24.2
	2	657	807	505	27.3
	6	654	836	642	20.0
	12	654	812	509	25.5
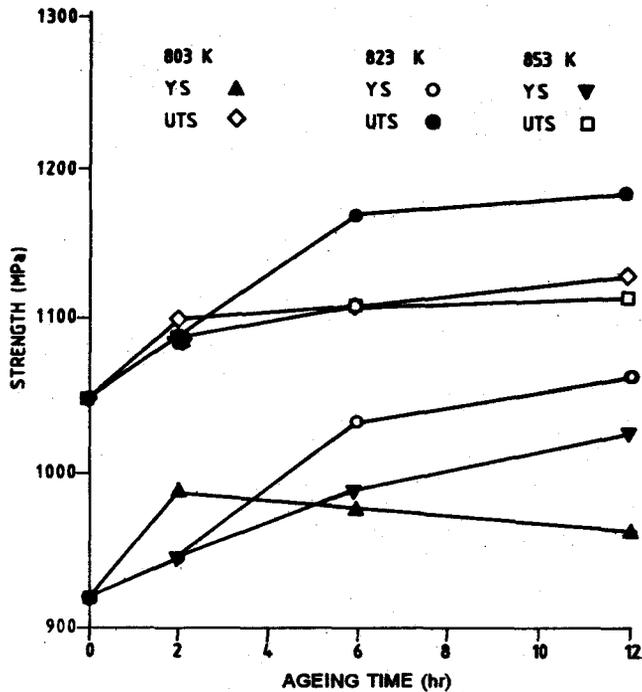
Figure 2. Variation of yield strength and tensile strength of VT9 with the time of ageing up to 12 hr at 803, 823 and 853 K following α + β solution treatment and air cooling, at room temperature.

Figure 3. Variation of yield strength and tensile strength of VT9 with ageing up to 24 hr at 823 K following α + β solution treatment and air cooling, at room temperature.

ageing curve. Figure 3 shows variation of yield strength and UTS with the period of ageing up to 24 hr. It is obvious that peak in strength occurs from ageing for 12 hr.

The strength and ductility values with the time of ageing at three different temperatures and at the elevated test temperature of 773 K are presented in Table 2. The variation in different values with the time of ageing at different temperatures, is shown in Fig. 4. It is obvious from the data in Table 2 and Fig. 4 that strength values are higher for the specimens aged at 823 K for 12 hr as compared to the values for the specimens aged according to the earlier reported stabilisation treatment (803 K for 6 hr)[1]. However, the increase in strength values, from ageing at 823 K for 12 hr in respect of the specimens aged at 803 K for 6 hr, at the test temperature (773 K) is relatively less than that observed at room temperature. The ductility values are nearly equal. It may be noted from the data in Tables 1 and 2 that ductility of the material is considerably higher at the test temperature of 773 K than that at room temperature.

4. DISCUSSION

It is thus obvious that tensile properties of VT9 from ageing at 823 K for 12 hr, following the solution treatment in the α + β phase field, are superior to those resulting from the earlier established stabilisation treatment (803 K for 6 hr)[1]. The stabilisation treatment, following the solution treatment either in the α + β or β phase field, is normally considered to relieve the stresses associated with solution treatment and subsequent cooling and to stabilise the microstructure. The residual stresses are expected to increase with the rate of cooling. A close examination of the data in Table 1 clearly shows that there is considerable increase in the strength values of the solution-treated specimens, following the ageing treatments at 803, 823 and 853 K. The yield strength and UTS of the solution-treated specimens are increased by as much as 15 per cent and 13 per cent, respectively due to ageing at 823 K for 12 hr. Thus, there is considerable strengthening of the material due to the so-called stabilisation treatment which otherwise is expected to relieve the
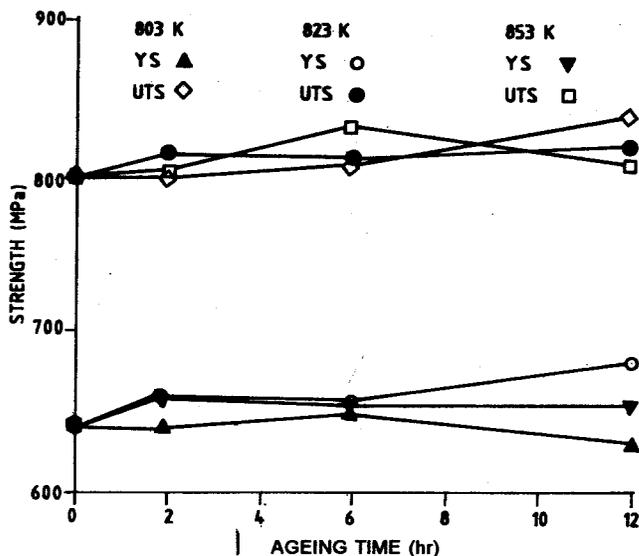
Figure 4. Variation of yield strength and tensile strength of VT9 with ageing up to 12 hr at 803, 823 and 853 K following α + β solution treatment and air cooling at 773 K.

residual stresses. In fact, mere removal of the residual stresses should have resulted in softening of the material. Further, it may be noted that both yield strength and UTS increases with the duration of ageing. Thus, it may be inferred that strengthening of VT9 from the ageing treatment is associated with a process of hardening like age hardening. Tempering of *Ti* alloys, following solution treatment, has been observed to cause transformation of the metastable β phase[6] that affects the strength.

The nature of transformation would depend upon the alloy composition and also the solution treatment and the subsequent rate of cooling. In the context of the ageing response of VT9, following α + β solution treatment and subsequent cooling in air, it is essential to examine the likelihood of phase instability in the alloy. As shown in Fig. 1, the α + β solution-treated sample shows a dual phase structure, consisting of the primary α and transformed β phases. As mentioned above, the transformed β phase consists of α laths and thin layer of β, retained between the α laths. There is less likelihood of any transformation in the α phase, in particular, the primary α phase. Strengthening of α phase alloys resulting from

ageing is normally associated with precipitation of the ordered α_2 phase (Ti_3Al), silicides of the type Ti_5Si_3 and various intermetallic compounds in the eutectoid[23] systems, such as *Ti-Cu*. Strengthening of the metastable β phase *Ti* alloys, resulting from ageing, generally occurs through precipitation of the lean β phase, ω phase, two types of α phases and various intermetallic compounds[23]. It has been established earlier[4], through transmission electron microscopy (TEM), that no precipitates are observed in the solution-treated condition of VT9, from ageing up to ~ 873 K. Precipitation of silicides $S_1[(TiZr)_5Si_3]$ and $S_2[(TiZr)_6Si_3]$, occurs above 873 K. The kinetics of silicide precipitation and the distribution of silicides, however, depends on the solution treatment and the subsequent rate of cooling. It is relevant to mention here that age hardening behaviour of VT9 (Fig. 3) at 823 K is similar to that observed earlier[24] in the near-α alloy IMI-685, which also did not reveal any distinct precipitate of silicides in the peak-hardened condition. However, careful examination through TEM revealed streaking in the diffraction spots, and hence it was inferred that there was tendency for short range ordering/zone formation from clustering of silicide forming elements[24] (*Zr & Si*). Thus, the observed strengthening in VT9, in which the kinetics of silicide precipitation is higher than that in the alloy[25] (IMI-685), may be attributed to initial stage of zone formation to cause subsequent precipitation of silicides. The zones are expected to be more effective in strengthening as compared to the incoherent silicide precipitates. The comparatively less increase in strength values resulting from ageing at 823 K, at the test temperature (773 K) compared to that at room temperature, may be attributed to less effectiveness of the zones, referred to above, on the motion of dislocations at the elevated temperature. There is less possibility of precipitation of Ti_3Al in this alloy under the conditions investigated in the present work, because of the short duration of ageing and faster rate of cooling, following the α + β solution treatment. Precipitation of Ti_3Al in this alloy was

observed on ageing for 24 hr at 823 K, following furnace cooling, after β solution treatment.

Since there is only marginal difference in the strength values of the specimens aged at 823 K for 6 hr with that for 12 hr, in view of the long duration of ageing, the appropriate stabilisation treatment was considered as ageing at 823 K for 6 hr.

It is relevant to mention here that stabilisation treatment of VT9 may have very detrimental effect on its UTS and ductility, following the solution treatment either in the α+β or particularly in the β phase field and quenching in water[2,26]. However, there is less influence of the ageing treatment at 823 K on ductility of the specimens, cooled at slower rates, following the solution treatment[26].

5. CONCLUSIONS

The earlier stabilisation treatment for VT9 consisted of ageing at 803 K for 6 hr, following the solution treatment in the (α + β)/β phase fields and cooling at room temperature. However, in the present investigation, it has been established through systematic investigations that ageing at 823 K for 12 hr, following solution treatment in the α + β phase field at 1233 K and air cooling, results in higher yield strength and UTS without any detrimental effect on ductility of VT9. Since there is only marginal improvement in the strength values from ageing at 823 K for 12 hr than that for 6 hr, the appropriate stabilisation treatment for this alloy, in view of the shorter duration, is adjudged ageing at 823 K for 6 hr. While there is considerable improvement in the strength values by the newly established stabilisation treatment (823 K for 6 hr) in comparison to the earlier one (803 K for 6 hr), at room temperature, there is less improvement in the strength values at the test temperature (773 K). The observed improvement in the strength values resulting from the stabilisation treatment appears to be associated with zone formation of the solutes.

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