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# PRELIMINARY MATERIAL PROPERTIES HANDBOOK

## Volume 1: English Units

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### 5.4.3 *Ti-6Al-2Sn-2Zr-2Mo-2CR-Si* (Ti-6-22-22S)

**5.4.3.0 *Comments and Properties*** —Ti-6-22-22S provides high strength in heavy sections with good fracture toughness and retains its strength up to moderate temperatures due to the addition of silicon. Ti-6-22-22S has improved strength and damage tolerance over Ti-6Al-4V.

*Thermomechanical Process Considerations* —The Ti-6-22-22S alloy can be fabricated into all forging product types, although closed die and precision forgings predominate. Ti-6-22-22S is commercially fabricated on all types of forging equipment under a range of processing temperatures.

Ti-6-22-22S is a reasonably forgeable alloy with comparable unit pressures (flow stress), forgability, and crack sensitivity to Ti-6Al-4V. Thermomechanical processes for the alloy use combinations of conventional (subtransus) and/or Beta (supra-transus) forging followed by subtransus and/or supra-transus thermal treatments to fulfill critical mechanical property criteria.

*Conventional Forging Considerations* —Conventional subtransus ($\alpha + \beta$) forging thermomechanical processes followed by a triplex $\beta$ heat treatment are the most widely used in commercial forging manufacture. To achieve conventional equiaxed $\alpha$ structures in preparation for final $\beta$ heat treatment, subtransus reductions of at least 50 to 75%, accumulated through one or more forging steps are required. Supra-transus $\beta$ forging may be used in the early forging operations such as upsetting or pre-forming. However, higher temperature initial forging operations must be followed by sufficient subtransus reduction to achieve an equiaxed $\alpha$ structure prior to heat treatment.

*Rolling, Forming, and Machining Considerations* — The rolling, forming, and machining behavior of Ti-6-22-22S are similar to those employed for processing of Ti-6Al-4V.

*Heat Treatment* — Ti-6-22-22S can be supplied in a number of heat-treated conditions depending on the mechanical property requirements. A list of potential heat treatments are shown below.

| | |
|---|---|
| Mill Anneal | 1350 – 1650°F (15 Minutes to 2 hours) |
| Solution Treat and Age (STA) | 1600 – 1700°F 15 to 60 Minutes AC or Faster, Age 900 – 1000°F 8 to 12 Hrs |
| Triplex Heat Treatment | ($\beta_T$ + 50°F) 30 Min. AC + ($\beta_T$ – 50°F) 1 Hr. AC + 1000°F 8 Hrs. AC |

*Specifications and Properties* — Material specifications are shown in Table 5.4.3.0(a). Room temperature mechanical and physical properties are shown in Table 5.4.3.0(b) and (c). Fracture toughness properties are shown in Table 5.4.3.0(d).

**Table 5.4.3.0(a). Material Specifications for Ti-6-22-22S**

| Specification | Form |
|---|---|
| AMS 4898 | Sheet |
| Boeing 5PTM7T01 (Proprietary) | Plate |

## Table 5.4.3.0(b). Typical Mechanical and Physical Properties of Ti-6-22-22S Sheet

| Specification | AMS 4898 | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Form | Sheet | | | | | | | | | | | |
| Temper | Annealed | | | | | | | | STA | | | |
| Thickness, in. | 0.016 to 0.032 | | | | 0.033 to 0.118 | | | | 0.032 to 0.063 | | | |
| | n/heats/ lots[a] | Avg. | Std. Dev. | Skew | n/heats/ lots[a] | Avg. | Std. Dev. | Skew | n/heats/ lots[a] | Avg. | Std. Dev. | Skew |
| Mechanical Properties: | | | | | | | | | | | | |
| TUS, ksi: | | | | | | | | | | | | |
| L | 16/4/4 | 164.9 | 4.3 | -0.83 | 30/6/14 | 165.8 | 3.3 | -0.25 | 18/2/7 | 195.0 | 3.0 | -0.36 |
| T | 16/4/4 | 165.8 | 4.2 | -0.44 | 30/6/14 | 170.4 | 4.5 | -0.11 | 18/2/7 | 190.6 | 6.1 | 0.28 |
| TYS, ksi: | | | | | | | | | | | | |
| L | 16/4/4 | 158.2 | 5.1 | -0.45 | 30/6/14 | 159.9 | 3.0 | 0.03 | 18/2/7 | 183.3 | 4.5 | 1.71 |
| T | 16/4/4 | 160.0 | 4.8 | -0.04 | 30/6/14 | 167.8 | 5.0 | 0.25 | 18/2/7 | 179.1 | 5.5 | 0.48 |
| CYS, ksi | – | – | – | – | – | – | – | – | – | – | – | – |
| SUS, ksi | – | – | – | – | – | – | – | – | – | – | – | – |
| BUS, ksi: | | | | | | | | | | | | |
| (e/D = 1.5) | – | – | – | – | – | – | – | – | – | – | – | – |
| (e/D = 2.0) | – | – | – | – | – | – | – | – | – | – | – | – |
| BYS, ksi: | | | | | | | | | | | | |
| (e/D = 1.5) | – | – | – | – | – | – | – | – | – | – | – | – |
| (e/D = 2.0) | – | – | – | – | – | – | – | – | – | – | – | – |
| *elong.*, percent: | | | | | | | | | | | | |
| L | 16/4/4 | 9.2 | 1.8 | -1.10 | 30/6/14 | 10.6 | 1.2 | -0.64 | 18/2/7 | 7.9 | 1.1 | -0.53 |
| T | 16/4/4 | 8.7 | 1.4 | -1.10 | 30/6/14 | 10.9 | 1.4 | 0.53 | 18/2/7 | 7.6 | 1.1 | -0.03 |
| *Red. of Area.*, percent: | – | – | – | – | – | – | – | – | – | – | – | – |
| $E$, $10^3$ ksi | 17 | | | | | | | | | | | |
| $E_c$, $10^3$ ksi | — | | | | | | | | | | | |
| $G$, $10^3$ ksi | — | | | | | | | | | | | |
| $\mu$ | — | | | | | | | | | | | |
| Physical Properties: | | | | | | | | | | | | |
| $\omega$, lb/in.$^3$ | 0.164 | | | | | | | | | | | |
| $C$, Btu/(lb)(°F) | – | | | | | | | | | | | |
| $K$, Btu/[(hr)(ft$^2$)(°F)/ft] | – | | | | | | | | | | | |
| $\alpha$, $10^{-6}$ in./in./°F | | | | | | | | | | | | |

a *n* represents the number of data points, *heats* represent the number of heats, *lots* represent the number of lots. Refer to Section 9.1.3 for definitions.

## Table 5.4.3.0(c). Typical Mechanical and Physical Properties of Ti-6-22-22S Plate

| Specification | Boeing specification 5PTM7T01 (Proprietary) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Form | Plate | | | | | | | |
| Condition (or Temper) | Triplex | | | | | | | |
| Thickness, in. | < 1 | | | | 1 up to 2 | | | |
| | n /heats /lots[a] | Avg. | Std. Dev. | Skew | n /heats /lots[a] | Avg. | Std. Dev. | Skew |
| Mechanical Properties: | | | | | | | | |
| *TUS*, ksi | | | | | | | | |
| L | 12/5/6 | 171.8 | 5.9 | -0.35 | 64/20/34 | 165.0 | 4.7 | -0.05 |
| T | 12/5/6 | 167.0 | 5.2 | 0.77 | 64/20/34 | 165.9 | 4.7 | -0.39 |
| *TYS*, ksi | | | | | | | | |
| L | 12/5/6 | 151.6 | 4.8 | 0.00 | 64/20/34 | 144.4 | 5.3 | -0.14 |
| T | 12/5/6 | 147.7 | 3.2 | -0.06 | 64/20/34 | 145.6 | 4.9 | -0.10 |
| *CYS*, ksi | | | | | | | | |
| L | – | – | – | – | – | – | – | – |
| T | – | – | – | – | – | – | – | – |
| *SUS*, ksi | | | | | | | | |
| L | – | – | – | – | – | – | – | – |
| T | – | – | – | – | – | – | – | – |
| *BUS*,ksi: | | | | | | | | |
| (e/D = 1.5) | – | – | – | – | – | – | – | – |
| (e/D = 2.0) | – | – | – | – | – | – | – | – |
| *BYS*, ksi: | | | | | | | | |
| (e/D = 1.5) | – | – | – | – | – | – | – | – |
| (e/D = 2.0) | – | – | – | – | – | – | – | – |
| *elong.*, percent | | | | | | | | |
| L | 12/5/6 | 9.2 | 1.0 | 0.14 | 64/20/34 | 9.0 | 1.6 | 1.35 |
| T | 12/5/6 | 9.0 | 1.0 | -0.57 | 64/20/34 | 8.8 | 1.7 | 1.32 |
| *Red. of Area*, percent | | | | | | | | |
| L | 12/5/6 | 11.7 | 1.0 | 0.13 | 64/20/34 | 12.9 | 2.4 | 0.83 |
| T | 12/5/6 | 13.8 | 3.5 | 0.06 | 64/20/34 | 13.6 | 2.4 | 0.68 |
| E, $10^3$ ksi [b] | 1/1/1 | 17.2 | – | – | 9/7/9 | 17.6 | 0.2 | -0.68 |
| $E_c$, $10^3$ ksi | – | | | | | | | |
| *G*, $10^3$ ksi | – | | | | | | | |
| $\mu$ | – | | | | | | | |
| Physical Properties: | | | | | | | | |
| $\omega$, lb/in.$^3$ | 0.164 | | | | | | | |
| *C*, Btu/(lb)(°F) | – | | | | | | | |
| *K*, Btu/[(hr)(ft$^2$)(°F)/ft] | – | | | | | | | |
| $\alpha$, $10^{-6}$ in./in./°F | – | | | | | | | |

a *n* represents the number of data points, *heats* represent the number of heats, *lots* represent the number of lots. Refer to Section 9.1.3 for definitions.

b Per ASTM E111-97.

**Table 5.4.3.0(c) Continued. Typical Mechanical and Physical Properties of Ti-6-22-22S Plate**

| Specification | Boeing specification 5PTM7T01 (Proprietary) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Form | Plate | | | | | | | |
| Condition (or Temper) | Triplex | | | | | | | |
| Thickness, in. | 2 up to 3 | | | | 3 - 4 (incl.) | | | |
| | n /heats /lots[a] | Avg. | Std. Dev. | Skew | n /heats /lots[a] | Avg. | Std. Dev. | Skew |
| Mechanical Properties: | | | | | | | | |
| *TUS*, ksi | | | | | | | | |
| L | 72/25/36 | 162.8 | 3.2 | 0.49 | 86/36/42 | 160.7 | 4.09 | 0.02 |
| T | 72/25/36 | 163.5 | 3.3 | 0.16 | 86/36/42 | 160.8 | 3.2 | -0.11 |
| *TYS*, ksi | | | | | | | | |
| L | 72/25/36 | 142.5 | 3.1 | 0.65 | 86/36/42 | 140.6 | 3.4 | 0.22 |
| T | 72/25/36 | 143.9 | 3.5 | 0.00 | 86/36/42 | 141.2 | 3.1 | 0.41 |
| *CYS*, ksi | | | | | | | | |
| L | – | – | – | – | – | – | – | – |
| T | – | – | – | – | – | – | – | – |
| *SUS*, ksi | | | | | | | | |
| L | – | – | – | – | – | – | – | – |
| T | – | – | – | – | – | – | – | – |
| *BUS*,ksi: | | | | | | | | |
| (e/D = 1.5) | – | – | – | – | – | – | – | – |
| (e/D = 2.0) | – | – | – | – | – | – | – | – |
| *BYS*, ksi: | | | | | | | | |
| (e/D = 1.5) | – | – | – | – | – | – | – | – |
| (e/D = 2.0) | – | – | – | – | – | – | – | – |
| *elong.*, percent | | | | | | | | |
| L | 72/25/36 | 9.5 | 1.8 | 0.40 | 86/36/42 | 9.2 | 1.9 | 0.26 |
| T | 72/25/36 | 9.4 | 1.8 | 0.27 | 86/36/42 | 9.0 | 1.7 | 0.35 |
| *Red. of Area*, percent | | | | | | | | |
| L | 72/25/36 | 14.0 | 2.4 | 0.22 | 86/36/42 | 14.0 | 2.3 | -001 |
| T | 72/25/36 | 13.6 | 2.2 | 0.15 | 86/36/42 | 13.7 | 2.3 | 0.04 |
| E, $10^3$ ksi[b] | 8/6/8 | 17.5 | 0.2 | -0.41 | 18/15/17 | 17.5 | 0.2 | -0.31 |
| $E_c$, $10^3$ ksi | – | | | | | | | |
| *G*, $10^3$ ksi | – | | | | | | | |
| $\mu$ | – | | | | | | | |
| Physical Properties: | | | | | | | | |
| $\omega$, lb/in.$^3$ | 0.164 | | | | | | | |
| *C*, Btu/(lb)(°F) | – | | | | | | | |
| *K*, Btu/[(hr)(ft$^2$)(°F)/ft] | – | | | | | | | |
| $\alpha$, $10^{-6}$ in./in./°F | – | | | | | | | |

a *n* represents the number of data points, *heats* represent the number of heats, *lots* represent the number of lots. Refer to Section 9.1.3 for definitions.

b Per ASTM E111-97.

## Table 5.4.3.0(d). Fracture Toughness Properties of Ti-6-22-22S Plate

| Specification . . . . . | Boeing specification 5PTM7T01 (Proprietary) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Form . . . . . | Plate | | | | | | | |
| Condition (or Temper) . . | Triplex | | | | | | | |
| Thickness, in. . . . . | < 1 | | | | 1 up to 2 | | | |
| | n /heats /lots[a] | Avg. | Std. Dev. | Skew | n /heats /lots[a] | Avg. | Std. Dev. | Skew |
| Mechanical Properties: $K_Ic$, ksi-in$^{0.5}$ T-L . . . . . | 7/5/6 | 97.0 | 8.1 | 1.14 | 35/20/31 | 89.6 | 8.2 | -0.27 |
| Thickness, in. . . . . | 2 up to 3 | | | | 3 - 4 (incl.) | | | |
| | n /heats /lots[a] | Avg. | Std. Dev. | Skew | n /heats /lots[a] | Avg. | Std. Dev. | Skew |
| Mechanical Properties: $K_Ic$, ksi-in$^{0.5}$ T-L . . . . . | 38/25/34 | 87.0 | 7.3 | -0.62 | 49/36/40 | 87.2 | 6.0 | -0.22 |

a *n* represents the number of data points, *heats* represent the number of heats, *lots* represent the number of lots. Refer to Section 9.1.3 for definitions.