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RESIDUAL STRESS MEASUREMENT OF TITANIUM - 6Al-4V
ALLOY PRESSURE VESSEL MATERIAL

National Aeronautic and Space Administration
Negotiated Contract

Contract No. NAS 9-9019

Control No. 8183005

Issuing Office: NASA Manned Spacecraft Center
R&D Procurement Branch
Houston, Texas 77058

Contract Negotiator: Mary Lou Crow/BG721(9), Buyer

Technical Monitor: R. E. Johnson/ES8

Contracted by: Texas Technological College
School of Engineering
P. O. Box 4289
Lubbock, Texas 79409

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Principal Investigator
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December 20, 1968

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NASA CR 92446

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
NEGOTIATED CONTRACT

Contract No.
NAS 9-9019

ISSUING OFFICE

Name NASA Manned Spacecraft Center

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School of Engineering

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Contract for

Amount

Study of Residual Stresses by X-ray Diffraction Techniques

\$3,000.00

Appropriation and other administrative data

Control number: 8183005 (complete)

Type of contract: Firm Fixed-Price Supply

Administration by: NASA Manned Spacecraft Center
R&D Procurement Branch
Houston, Texas 77058

Appropriation and allotment chargeable: 914-50-20-21-ES-2511-ES81-2P067-2POMA
80X0108

Priority Rating: DO-A2 Certified under DMS Reg. No. 1.

Contract Negotiator: Mary Lou Crow/BG72 (9), Buyer, Telephone: A/C 713, 483-5441

Technical Monitor: R. E. Johnson/ES8, Telephone: A/C 713, 483-2059

This negotiated contract is entered into pursuant to the provisions of 10 U.S.C. 2304 (a)(5) and any required findings and determination have been made.

THIS CONTRACT is entered into as of _____ by and between the United States of America, hereinafter called the Government, represented by the Contracting Officer executing this contract, and Texas Technological College.

- (i) a corporation organized and existing under the laws of the State of N/A
- (ii) a partnership consisting of N/A
- (iii) an institution of higher education

hereinafter called the Contractor. The parties hereto agree that the Contractor shall furnish and deliver all supplies and perform all the services set forth in the attached Schedule, for the consideration stated herein.

Statement of Work

When a polycrystalline piece of metal is deformed elastically in such a manner such that the strain is uniform over relatively large distances, the lattice plane spacings in the constituent grains change from a stress-free value to some new value corresponding to the magnitude of the applied stress; this uniform macrostrain causes a "shift" of the diffraction lines to new 2θ positions. In such a manner the surfaces of 6Al-4V titanium alloy weldments and parent metal were analyzed by the use of a General Electric XRD-5 Diffractometer utilizing Brentano Parafocusing technique and a General Electric CA-7 Copper Diffraction Tube at Texas Technological College for the nondestructive measurement of directional elastic residual stresses.

In general, compressive stresses were found on both surfaces of the samples, although in some samples, tensile stresses were observed in welds and heat affected zones.

Examination of a weldment where large offsets or mismatch occurred during welding showed high tensile residual stresses in the cross-section exceeding the uniaxial yield strength of the material. Stresses of this magnitude could be quite important in crack propagation analysis.

Delivery

Work contracted by the contractor has been completed before December 31, 1968, and constituted partially the data and interpreted results submitted to the Technical Monitor, Mr. R. E. Johnson/ES8, in an MSC Internal Note IN-68-Es- Engineering and Development, entitled "Residual Stress Measurement of 6Al-4V-Titanium Alloy Pressure Vessel Material."

Government-Furnished Property

The specimens furnished by NASA-MSD which include:

- A. Weldments of forged and machined sections
- B. Misaligned weldments
- C. Edge cracked
- D. 301 Burst welded spherical tank

have been returned to the Technical Monitor, Mr. R. E. Johnson/ES8, along with chart recordings and calculations.

Exhibit "A"

Stress Measurement by X-Ray Diffraction

The directional macro-elastic residual surface stresses in the following specimens from Ti-6Al-4V tanks solution treated (1/2 hour at 1725°F, W.Q.), aged (4 to 10 hours at 950° to 1150°F, A.C.) welded and stress relieved (4 hours at 1000°F in air) were obtained by back-reflection of (213)- α titanium at 142.80 degrees 2 θ with Cu K α radiation at 45 Kv and 14 ma (with 0.00035" Ni-filter). The sense and magnitude of the residual elastic stresses were obtained from the diffraction maxima of (213) α - titanium oriented at parafoal position and also at 45 degree tilt from the parafoal position.

The specimens furnished by NASA-MSc included the following conditions:

Ti-6Al-4V

A. Weldments of forged and machined sections

Three specimens will be X-rayed on both sides for

- (i) weld stress
- (ii) stresses in the heat affected zones on both sides of weld
- (iii) stresses in the smooth parent sections remote from weld

B. Misaligned Weldments

One each to represent an example of badly misaligned welds. welds misaligned to a minor degree, and no visible misalignment in the weld

C. Edge Cracked

In order to evaluate residual elastic stresses at the tip of advancing cracks a piece of a forged section was notched at the edge and subjected to repeated stress cycles. Surface adjacent to the advancing crack tips was X-rayed on both sides.

D. 301 Bursted Welded Spherical Tank

One fractured piece and one weldment and its heat affected zones of a bursted cryogenically ardeformed 301 stainless steel tank were X-rayed on both sides for (222) of austenite and (211) of ferrite with Cr-K α at 45 Kv and 14 ma (V-filter).

The work was conducted using the General Electric XRD-5 diffractometer and X-ray stress measurement attachment. Results, including experimental data were submitted to the Technical Monitor, Mr. R. E. Johnson/ES8, as a part of NASA-MSc Internal Note IN-68-ES- Engineering and Development, entitled "Residual Stress Measurement of 6Al-4V-Titanium Alloy Pressure Vessel Material." The following five pages describe pertinent data and their interpretation.

TABLE II
(213)1, Line Shift Data on Stressing

1. Badly Misaligned TW2 Specimen Location	Side A		Side B		Parent Metal
	Weld	U.H.A.Z.	U.H.A.Z.	L.H.A.Z.	
20 ₁ , degrees	140.63	141.91	142.78	143.91	142.76
20 ₄₅ , degrees	142.16	142.16	143.40	143.86	144.20
σ_ϕ , psi	-111,700	-165,000 *	-45,200	3,600	-115,000
2. Badly Misaligned No. 134 Specimen Location	Weld	U.H.A.Z.	U.H.A.Z.	L.H.A.Z.	Parent Metal
20 ₁ , degrees	142.62	142.95	142.22	142.23	142.11
20 ₄₅ , degrees	144.05	144.04	144.68 *	144.46 *	144.58
σ_ϕ , psi	-104,200	-79,500	-179,600	-162,700 *	-180,200
3. Badly Misaligned No. 132 Specimen Location	Weld	U.H.A.Z.	U.H.A.Z.	L.H.A.Z.	Parent Metal
20 ₁ , degrees	140.67	139.21	143.29	142.70	
20 ₄₅ , degrees	143.07 *	140.98	144.30	144.03	
σ_ϕ , psi	-175,200	-129,200	-73,800	-97,200	
4. Slightly Misaligned No. 195 Specimen Location	Weld	U.H.A.Z.	U.H.A.Z.	L.H.A.Z.	Parent Metal
20 ₁ , degrees	142.33	143.14	142.15	141.80	
20 ₄₅ , degrees	143.46	144.04	144.82 *	144.25 *	
σ_ϕ , psi	-82,500	-65,600	-195,000	-170,000	
5. No Visible Misalignment No. 14 Specimen Location	Weld	U.H.A.Z.	U.H.A.Z.	L.H.A.Z.	Parent Metal
20 ₁ , degrees	141.08	139.57	143.18	139.51	143.00
20 ₄₅ , degrees	143.37 *	145.02 *	144.36	144.07 *	144.52
σ_ϕ , psi	-166,400	-398,000	-86,100	-333,500	-111,000
6. 50 percent Reduced Central Section. Badly Misaligned, VIR Specimen Location	Weld	U.H.A.Z.	U.H.A.Z.	L.H.A.Z.	Parent Metal
20 ₁ , degrees	142.36	142.96	143.14	143.08	143.02
20 ₄₅ , degrees	143.21	143.95	144.06	140.56 *	144.10
σ_ϕ , psi	-62,000	-72,200	-67,100	181,000	-63,500

* Extrapolated formula value, fictitious and not true.

7. Weld Partly Ground Off vs Full Weld, Badly Misaligned. VIR

Specimen Location	Full Weld	Weld Partly Ground Off
20 _L , degrees	141.45	141.85
20 ₄₅ , degrees	142.96	143.03
σ_{ϕ} , psi	-110,000	-86,300

8. As Received TMCA Ti Alloy Sheets

Alloy	Lot No.	K3	Thickness	Side A	
				20 _L , deg.	20 ₄₅ deg.
Ti 75	G9559	7.55 x 10	0.025"	140.39	141.56
Unmarked	G7346	7.30 x 10	0.040"	141.91	143.25
					σ_{ϕ} , psi
					-88,300
					-97,800

Side B	
20 _L , deg.	20 ₄₅ , deg.
140.42	141.49
141.88	142.79
	σ_{ϕ} , psi
	-80,700
	-66,400

9. Fracture Tank Piece, Ti-6Al-4V

Test	Date	Spot	Side	20 _L , deg.	20 ₄₅ , deg.	σ_{ϕ} , psi
1	5/31/68	1	A	142.62	143.03	-29,900
		2	A	142.61	143.10	-35,800
		3	A	142.63	143.05	-30,700
		4	B	142.59	143.21	-45,300
2	7/14/68	3	A	142.77	144.00	-89,800
		4	B	143.04	144.12	-78,800

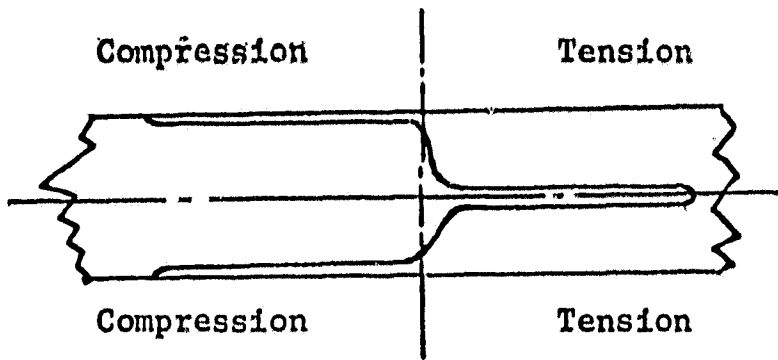


Figure 4a

Surface compressive stress
balanced against high mid-
section tensile stress

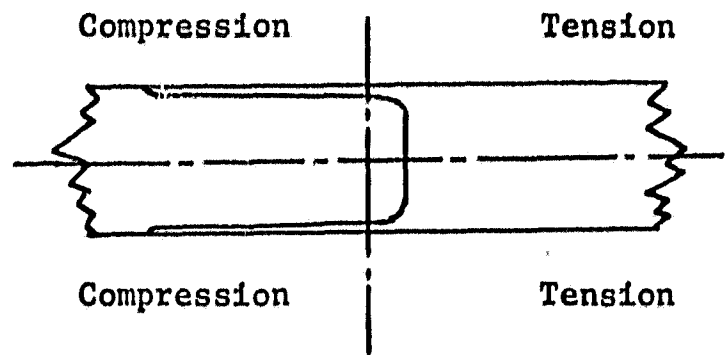


Figure 4b

Surface compressive stress
balanced against low mid-
section tensile stress

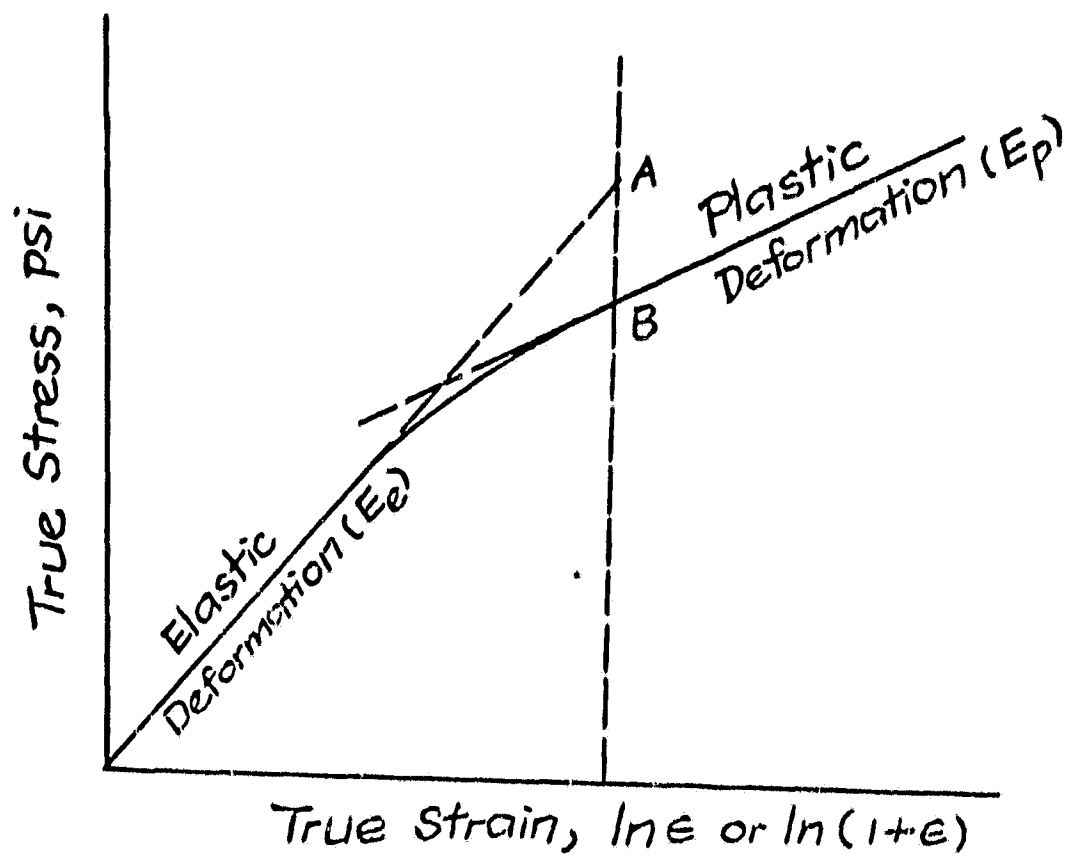


Figure 5

True stress - True strain curve of Ti-6Al-4V

A-fictitious stress calculated from $\sigma_\phi = K_3 \Delta 2\theta$ where $E = E_e$

B-Actual stress where $E = E_p$