DSIAC TECHNICAL INQUIRY (TI) RESPONSE REPORT

Historical Rationale for Design Restrictions on D6AC Steel in U.S. Aerospace Structures

Report Number:
DSIAC-2019-1118
Completed June 2019

DSIAC is a Department of Defense Information Analysis Center

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DSIAC Defense Systems Information Analysis Center

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
17-06-2019	Technical Research Report	

4. TITLE AND SUBTITLE

Historical Rationale for Design Restrictions on D6AC Steel in U.S. Aerospace Structures

5a. CONTRACT NUMBER
FA8075-14-D-0001

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

Jennifer Flores-Lamb and Doyle T. Motes

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Defense Systems Information Analysis Center (DSIAC)
Texas Research Institute Austin, Inc.
415 Crystal Creek Drive
Austin, TX 78746

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Defense Technical Information Center (DTIC)
8725 John J. Kingman Rd.
Ft. Belvoir, VA 22060-6218

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT

Approved for public release: distribution unlimited.

13. SUPPLEMENTARY NOTES

Technical Areas: materials and manufacturing processes; air platforms

14. ABSTRACT

The Defense Systems Information Analysis Center (DSIAC) received a technical inquiry requesting information regarding the field experience that caused D6AC steel to be listed as a restricted material in NAVAIR EC-434-000-003. We performed literature searches using the Defense Technical Information Center, open sources, and university libraries to determine that specifically, the F-111 failure of 22 December 1969 was the primary reason for D6AC steel becoming a restricted material.

15. SUBJECT TERMS

Steel, D6AC steel, aerospace materials, F-111, fatigue, stress corrosion cracking

16. SECURITY CLASSIFICATION OF: U			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE	UU	10	Ted Welsh, DSIAC Director
U	U	U			19b. TELEPHONE NUMBER *(include area code)* 443-360-4600

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39.18

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A chief service of the DoD IACs is free technical inquiry (TI) research, limited to 4 research hours per inquiry. This TI response report summarizes the research findings of one such inquiry jointly conducted by DSIAC.

ABSTRACT

The Defense Systems Information Analysis Center (DSIAC) received a technical inquiry requesting information regarding the field experience that caused D6AC steel to be listed as a restricted material in NAVAIR EC-434-000-003. We performed literature searches using the Defense Technical Information Center, open sources, and university libraries to determine that specifically, the F-111 failure of 22 December 1969 was the primary reason for D6AC steel becoming a restricted material.

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1.0 TI Request

1.1 INQUIRY

What is the reason behind D6AC steel being listed as a restricted material?

1.2 DESCRIPTION

The inquirer requested information on the field experience that caused D6AC steel to be listed as a restricted material in NAVAIR EC-434-000-003.

2.0 TI Response

The Defense Systems Information Analysis Center (DSIAC) received support from Mr. Doyle T. Motes, P.E., who is a subject matter expert (SME) in materials science and engineering from Texas Research Institute Austin (TRI Austin). Mr. Motes performed a literature search using a combination of open sources, the Defense Technical Information Center (DTIC), and university library resources to produce an answer to the technical inquiry.

2.1 D6AC STEEL

D6AC is considered a medium-carbon (0.4−0.5 wt.%), ultra-high-strength, aerospace steel alloy. It is designed for high-strength structural applications requiring tensile strengths up to 280 ksi and provides a high yield-strength to tensile-strength ratio, combined with good ductility. A tough and fibrous fracture is exhibited at as low as -210 °F (134 °C) for impact testing, and the notch toughness is noted to be excellent. This material has been selected for fracture toughness critical applications at a variety of strength levels. The deep hardening characteristics of D6AC steel make it applicable for production of fairly large sections of material [1]. In addition, the material is weldable, even in heavy sections. However, D6AC steel is susceptible to fatigue and stress corrosion cracking. A selection of mechanical material properties for D6AC is listed in Table 1.

Table 1: Mechanical Properties of D6AC Steel [1]

Tempering Temp		Tensile Strength		0.2% Yield Strength		Elongation	Reduction of Area	Hardness
°F	°C	ksi	MPa	ksi	MPa	(%)	(%)	Rockwell C Hardness (HRC)
600	316	280	1,931	250	1,724	7	23	53
950	510	228	1,572	195	1,345	7	25	46

2.2 NAVAIR EC-434-000-003

NAVAIR EC-434-000-003 is a specification/standard relating to Material Selection Restrictions for Navy and Marine Corps Aviation Weapon Systems. D6AC steel is employed in a number of weapon systems (especially legacy ones), including the F-111, F-14, H-53E, and E-2C, and is listed as a restricted material in the NAVAIR document.

2.3 RATIONALE BEHIND RESTRICTIONS ON D6AC STEEL

The main rationale behind the D6AC use restrictions is associated with the F-111 program. Cracks in the F-111's D6AC wing attach points were first discovered in 1968 during ground fatigue testing. Afterwards, on 22 December 1969, the left wing pivot fitting of U.S. Air Force F-111 No. 94 aircraft failed during a 4.0 Gee pull-up maneuver out of a practice bombing run at Nellis Air Force Base in Nevada, causing the loss of the left wing. The cause of the failure, resulting in the loss of the aircraft and crew of two, was attributed to the presence of a manufacturing defect (a forging lap) in the D6AC steel pivot fitting [2, 3].

Flight testing associated with this issue continued through 1973. Investigations conducted in the 1970s revealed the cause of failure of the F-111 to be fracture of D6AC steel in the wing pivot fitting due to manufacturing defects missed by conventional nondestructive inspection (NDI) methods available at the time [3]. Critical F-111 structural components fabricated from D6AC steel included the wing pivot fitting, the wing carry through box, major fuselage frames and longerons, as well as the more conventional nose and main landing gear. Mitigation measures to address these problems are denoted by Watters et al., who state that "…the investigations and research into D6AC steel characteristics developed a new discipline called 'Fracture Mechanics'"[3]. These concerns continued through 1980s and 1990s for United States operators of the aircraft, and into the 2000s after the United States retired the aircraft and during the period where it was exclusively operated by the Australian Air Force. Lax stated that "aside from the SCC [stress corrosion cracking] problem, the main corrosion concern for the F-111 is for pitting corrosion to initiate fatigue cracks, and D6AC steel is the material of most concern" [4].

In addition to these findings, and complicating factors, the type of defect that led to the 1969 crash of the F-111 was one that was repeatedly missed by NDI during fabrication, as discussed by Forney: "The resulting investigation during 1970 revealed the cause to be the catastrophic fracture of the D6ac high strength steel outer wing pivot fitting due to the presence of a manufacturing-introduced one inch surface crack that had been missed repeatedly by NDI during fabrication..." [5].

Additionally, the 2015 version of MIL-STD-1568D, which establishes the requirements for materials, processes, and techniques, and identifies the tasks required to implement an

effective corrosion prevention and control program throughout the conceptual, validation, development, production, and sustainment phases of the aerospace weapons systems life cycles, also lists D6AC, H-11, 4340M, and 300M steels as materials that are not to be used [6]. An example of the change from the use of D6AC steel to Ti 64 on aircraft is shown in "The Development of the F-14A Wing Center Section" [7], in which the wing pivot structure material has been changed from D6AC steel on the F-111 to Ti 64 on the F-14.

2.4 SUMMARY

D6AC steel is susceptible to fatigue cracking and stress corrosion cracking, despite the impressive tensile and yield strengths that can be achieved for different heat treatments. It is for these reasons that it is listed as a restricted material in EC-434-000-003.

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BIOGRAPHIES

Doyle Motes is a licensed professional engineer in Texas and is employed as a research engineer at TRI Austin, Inc. He has extensive experience and has published in the fields of pulsed power, materials engineering and processing, and nondestructive testing. His research interests include additive manufacturing and 3-D printing, materials engineering and processing, nondestructive testing (in particular, ultrasound and eddy current testing), sustainment of aging weapon systems, automation of inspection/validation technologies, and materials state sensing. Mr. Motes holds bachelor's and master's degrees in mechanical engineering from the University of Texas at Austin.

Jennifer Flores-Lamb has been a Nondestructive Inspection Specialist at TRI, Austin, Inc. since 2011. She has experience in a wide range of nondestructive inspection techniques including ultrasonic testing, eddy current/electromagnetic testing, magnetic particle testing, and liquid penetrant testing. Her research interests include aging aircraft and effects of damage (fatigue cracking and corrosion) on aging aircraft readiness. She is a member of the American Society of Nondestructive Testing (ASNT) and holds an associate's degree in this field from Del Mar College in Corpus Christi, Texas.