ALLOY 718 FASTENERS

VERSATILITY AND RELIABILITY FOR AEROSPACE DESIGN

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Abstract

Alloy 718 mechanical fasteners will be shown to provide solutions to a variety of high performance fastening problems. These range from use in jet engines, which utilize their high temperature properties, to use at 220 ksi minimum ultimate tensile strength in airframe applications where they have provided a virtually universal alternative to stress-corrosion cracking prone H-11 fasteners. Some factors which must be considered in successful application are discussed. Among these are ductility in the high strength condition and galvanic compatibility with structural materials.

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Introduction

Since its introduction in 1958, Alloy 718 has found application in a broad spectrum of industries, environments, configurations, and conditions. Nowhere has this versatility been more successfully exploited them in mechanical fasteners. Alloy 718 fasteners have been used on virtually every commercial and military aircraft program as well as in nuclear power plants, the petrochemical and chemical industries, space vehicles, missiles and other areas requiring its unique combination of properties. Recently Alloy 718 has become the material of choice for applications formerly employing H-11 (AMS 6487) fasteners because of the susceptibility of H-11 fasteners to stress-corrosion cracking.

Early Applications

Originally developed as a high temperature material, Alloy 718 found its first application in gas turbine engine components where its high tensile and yield strength and creep properties permitted its use in the 800°F to 1200°F range. The demand for jet engine fasteners which could provide and maintain high clamp loads at high temperature led to the selection of Alloy 718 for many fastener applications especially when the structure was Alloy 718. This selection provided a thermal expansion coefficient match between the structure and the fastener and prevented loss or gain in preload resulting from temperature excursions. Excellent experience with Alloy 718 fasteners has led to their wide spread use by all the major gas turbine engine manufacturers. Structural designers began to turn to Alloy 718 when in need of fasteners with excellent corrosion resistance and tensile strengths in the area of 180,000 psi to replace alloy steel fasteners when the cost increase could be justified by the increased reliability. In addition to increased corrosion resistance, the Alloy 718 fasteners provided excellent resistance to hydrogen embrittlement and stress-corrosion cracking and excellent cryogenic properties. At this point, the Alloy 718 fasteners were produced in the conventional solution treated and aged condition. Most of these were used in the aerospace, chemical, petrochemical and nuclear industries. The most notable of these was the application on the Space Shuttle where two fastener materials were selected for the structure which attaches the three liquid engines to the orbiter. The two materials were Alloy 718 and MP35N® Alloy with Alloy 718

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being selected where 180 ksi tensile strength was adequate for the design and where fastener diameters up to 2" were required. The selection of these materials was based on concern for the exposure of highly loaded fasteners to the high humidity and salty environment of the launch site. These fasteners have helped make the space shuttle orbiter re-usable with little structural maintenance between missions.

In the late 1960's, materials and processes were developed to produce Alloy 718 fasteners with minimum ultimate strengths of 220,000 psi. These were made by a process involving cold reduced and aged material (no intermediate solution heat treatment). These fasteners found limited applications in airframe, but did not then become commonplace because of their somewhat higher cost compared to H-11 (AMS 6487) fasteners which made up the majority of 220,000 psi fasteners (and 260,000 fasteners as well).

H-11 History

Fasteners made from H-11 were developed in the late 1950's and were used on virtually every airframe where the design required 220,000 psi or 260,000 psi minimum ultimate tensile strength. The selection of H-11 was based primarily on fatigue strength, the fatigue strength of H-11 being somewhat better than that of competing materials. There was some concern about stress-corrosion cracking but since all the candidate materials shared a susceptibility, H-11 became the nearly universal choice. There were no corrosion resistant materials available which could achieve the mechanical properties of H-11.

Stress-corrosion cracking results from a combination of three factors:

(1) Material Susceptibility - Lack of general corrosion resistance is a major contributor to this factor although specific aspects of corrosion such as pitting and crevice corrosion may be more influential since most stress-corrosion cracks initiate in the bolt shank where localized attack occurs as a result of crevice conditions.

(2) Corrosive Environment - This can vary from an environment rich in chlorides such as found near bodies of salt water to those involving normal humid air depending on the susceptibility of the material.

(3) Stress - This is provided primarily by the preload induced in the bolt by tightening. Some additional service loads may contribute, but are usually not significant.

These factors combine to produce a surface pit which provides the initiation site for the crack which propagates perpendicular to the bolt axis at a slow rate. When the crack has grown to the point where the uncracked material can no longer support the bolt load, failure occurs. The extent to which the crack grows before failure is strongly dependent on the fracture toughness of the material. Thus for a given material, susceptibility to stress-corrosion cracking increases with increasing material strength. This is certainly the case with H-11, the 260 ksi strength level being more susceptible than the 220 ksi level. Figure 1 shows a photograph of typical stress-corrosion cracking. A great deal of research was directed toward the development of coatings which would prevent stress-corrosion cracking in H-11 fasteners (1). A few of them provided some improvement over the commonly used coatings (vacuum deposited cadmium on 260,000 psi bolts and fluoborate cadmium on 220,000 psi bolts) but no practical coatings were able to prevent early failures in alternate immersion tests performed in accordance with Military Standard 1312, test 9 (2). The results of a few of the coatings are shown in Figure 2. It is obvious from these results that no coating provides immunity to stress-corrosion cracking.

Faced with no viable alternatives, the aerospace industry continued the extensive use of H-11 fasteners through the middle of the 1980's. While the use of H-11 continued, several factors were contributing to its demise.

(1) Sporadic stress-corrosion cracking failures continued.

(2) There was an increase in the emphasis on product liability.

(3) A data base on the use of high strength corrosion resistant fasteners was developing.

(4) The increased knowledge of joint design led to an increased awareness of the importance of proper, usually high, preloads. Bolts of H-11, thus tightened, were more likely to fail under the higher stress conditions.

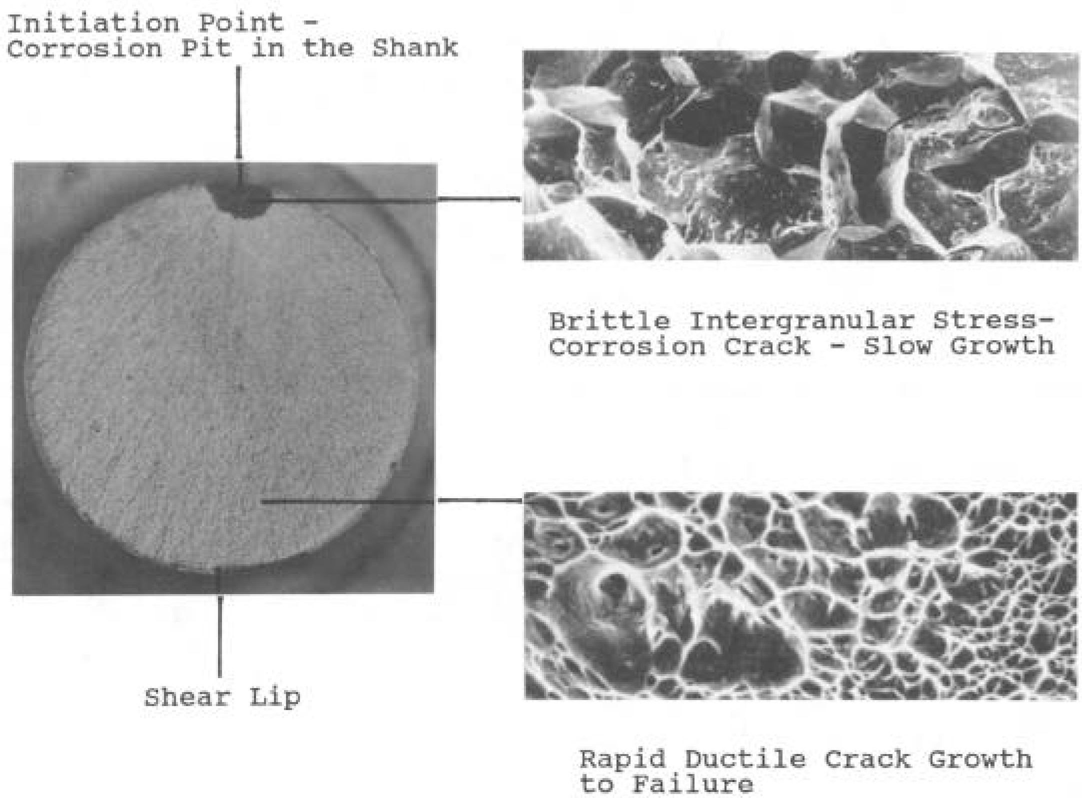

Figure 1. Typical stress-corrosion fracture of a high strength H-11 bolt.

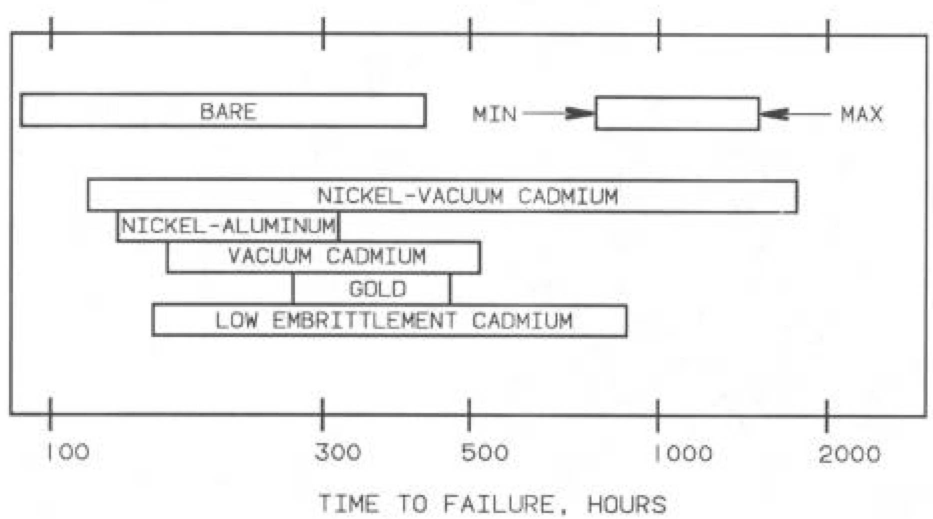

Figure 2. Effect of coatings on stress-corrosion cracking resistance of 260,000 psi H-11 bolts tested per MIL-STD-1312, test 9.

These and other factors combined to cause the aerospace industry to take firm action against the use of H-11 fasteners in critical applications. Some companies prohibited their use in new design, others changed existing designs to prohibit their use, while still others mandated the rhetrofit of existing fasteners with those of corrosion resistant materials.

Corrosion Resistant Fasteners for 220,000 psi and 260,000 psi Tensile Strength

The primary candidates for the 220,000 psi fasteners were Alloy 718 in the cold worked and aged condition and PH13-8Mo in the H950 condition. Alloy 718 was found to be the more reliable choice since PH13-8Mo is susceptible to hydrogen embrittlement/stress-corrosion cracking in the H950 condition when coupled to active materials such as aluminum (3). The candidates for the 260,000 psi fasteners were MP35N® Alloy and MP159® Alloy, two materials developed specifically for corrosion and stress-corrosion resistance and high tensile and fatigue properties.

Table 1 summarizes the options for high strength corrosion resistant fasteners.

TABLE 1

Minimum Mechanical Properties of
Bolts Made from Corrosion Resistant Materials

Material	Condition	Bolt Properties: Ultimate Tensile Strength (MPa)	Bolt Properties: Ultimate Tensile Strength (ksi)	Base Metal Properties: UTS (MPa)	UTS (ksi)	Yield (MPa)	Yield (ksi)	Elong (%)	RA (%)
A-286	S T & A *	896	130	896	130	586	85	15	20
	C W & A **	1103	160	1103	160	1020	120	12	18
	C W & A	1240	180	1240	180	1034	150	10	18
	C W & A	1379	200	1379	200	1240	180	8	15
Alloy 718	S T & A	1240	180	1240	180	1034	150	12	15
	C W & A	1517	220	1517	220	1379	200	8	15
MP35N®	C W & A	1793	260	1793	260	1586	230	8	35
MP159®	C W & A	1793	260	1793	260	1724	250	6	22

* S T & A = solution treated and aged.
** C W & A = cold worked and aged.

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Alloy 718

Alloy 718 has replaced H-11 as the material of choice for optimum joint integrity when the minimum tensile strength requirement is 220,000 psi. The method of manufacture involves the introduction of a critical amount of cold work into the material either during bar/wire production or during the fastener manufacture. A precipitation hardening operation, without prior solution heat-treatment results in the required tensile strength. Minimum material tensile properties of the finished product are as follows:

Ultimate tensile strength	- 220,000 psi
0.2% offset yield strength	- 200,000 psi
Elongation	- 8%
Reduction of area	- 15%

While properly controlled manufacture produces fasteners which have a high degree of reliability, care must be exercised to avoid excessive cold work since Alloy 718 experiences a severe drop in ductility as its tensile strength increases. This is shown in Figure 3.

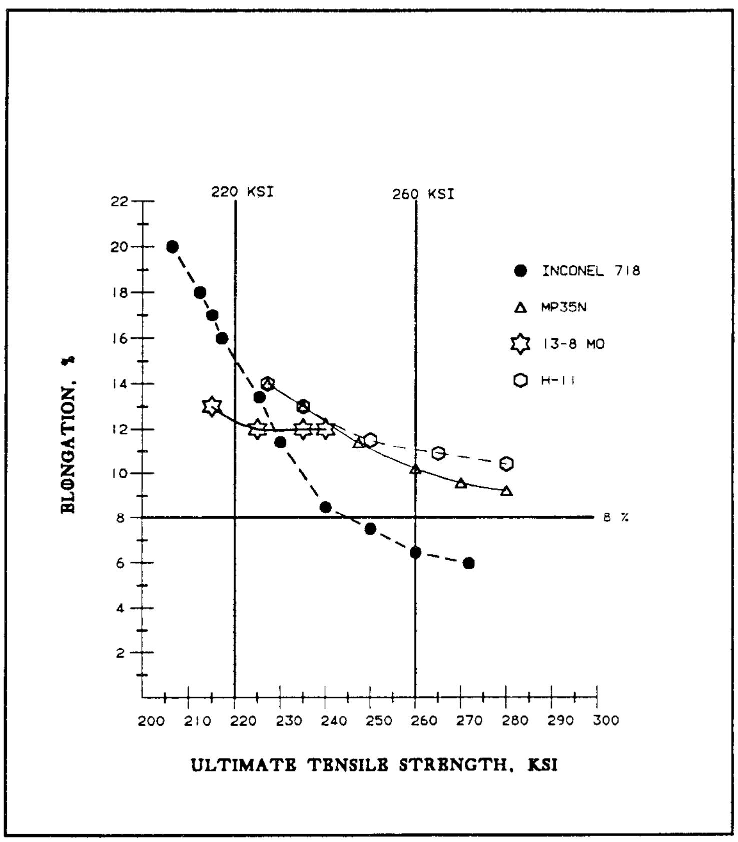

Figure 3. High strength bolt alloys. Ultimate tensile strength vs. elongation

Service failures have occurred when Alloy 718 fasteners with tensile strengths above 260,000 psi were used. Alloy 718 fasteners should not be used if the ductility can not be demonstrated to be as above, 8% minimum elongation, 15% reduction of area. This should be demonstrated either by testing specimens made from the fasteners or by testing specimens processed in exactly the same manner as the fasteners. This latter option may not be possible if the cold work is introduced during the manufacture of the fastener.

Stress-corrosion tests of Alloy 718 fasteners in accordance with MIL-STD-1312, test 9, have been continued for extended periods of time with no failures.

Fatigue resistance of Alloy 718 fasteners is equivalent to that of H-11.

Shear strength of Alloy 718 fasteners is 125,000 psi compared to 132,000 psi for H-11 fasteners.

Applications of 220,000 psi Alloy 718 fasteners include some of the most critical areas in airframe structure such as engine mounts, wheels and wing attachments. The current size range is from #10 (3/16") to 1-1/2" diameter.

The excellent corrosion resistance of Alloy 718 fasteners creates a galvanic compatibility problem when they are used in aluminum structures. This did not exist with H-11 fasteners since they were coated with cadmium for protection of the fastener and thus were well matched to the aluminum structure. In the case of Alloy 718, a significant galvanic cell exists between it and aluminum depending on the environment. To prevent galvanic corrosion, Alloy 718 fastener can be coated with a sacrificial material to match it to the structure. Some coatings used are:

(1) Cadmium deposited from a cyanide bath.
(2) Cadmium deposited from a fluoborate bath.
(3) Vacuum deposited cadmium.
(4) Ion vapor deposited aluminum.
(5) Aluminum rich paints - aluminum in an organic binder.

All of the above provide galvanic matching. The choice is based on cost, frictional characteristics, adhesion and other factors. The most commonly used are electroplated cadmium (1 and 2) and aluminum rich paints.

When Alloy 718 fasteners are used in applications not requiring galvanic matching, it is essential that provisions be made to provide lubrication which will prevent galling of the threads during installation. This is usually provided by silver plating, dry film lubricants or a combination of the two. When a nut is used it can be silver plated and coated with a dry film lubricant for optimum installation. If the female thread is a tapped hole in the structure, some provision must be made for lubrication on the bolt.

Summary

Alloy 718 has become one of the most versatile of fastener materials, evolving from a material with a narrow range of use to one whose applications range from liquid hydrogen temperature (-423°F) to 1200°F. Applications include success stories in a multitude of industries with the alloy now being extensively applied in advanced aerospace programs such as the V-22 Osprey, MD-11 and C-17 not only in the engines, for which it was originally developed, but in a multitude of critical joints throughout the airframes.

References

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