

Influence of Grain Flow on Bolt Integrity

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INTRODUCTION

Many of the military and aerospace company bolt specifications have a requirement concerning grain flow in the head of forged bolts. The requirements are of two types. One uses photomicrographs to illustrate what is considered "acceptable" and what is "unacceptable". An example of this is AS7471, which covers Waspaloy, but the photomicrograph is of a steel bolt. Waspaloy is a vacuum melted material that is solution treated after it is headed. This recrystallization thermal process wipes out grain flow pattern as the deformed grains are eliminated. In addition the relatively small amount of inclusions, compared to an air melt steel, make it difficult to determine where the flow lines were. For these reasons an air melt steel bolt was used for the photomicrograph examples. This difficulty of determining grain flow in a finished bolt exists for all vacuum melted materials such as IN718 and titanium alloys.

Other specifications avoid the difficulty of determining the flow pattern of heat treated parts from a photomicrograph by using sketches. The origins of the sketches go back over forty years when they were drawn for commercial cold headed bolts. Prior to the development of cold headers just before WWII, all bolts under about 1/2 inch were made on screw machines. The steels used were "dirty" which allowed very fast cutting. These steels were unacceptable for cold heading because the stringers caused splitting. The cleaner steels required for cold heading began to be preferred by the users due to the superior characteristics of the clean material. Sketches were added to the specifications showing an upset pattern for a headed bolt. These sketches became part of the military and early aircraft specifications and are unchanged today. A close look reveals that there are no "flow" lines near the outer diameter of the heads. The reason is that they never were made to illustrate exactly how the metals flowed but merely that the part was forged.

As new alloys began to be used the sketches did not change to reflect any change in forging characteristics. The actual flow pattern of materials depends on the lattice structure such as bcc, fcc or cph and this is further complicated by texturing developed from coldworking of the thermo-mechanically treated materials such as A286, IN718 and MultiPhase alloys.

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INTRODUCTION (Continued)

A part of the flow line requirements is the prohibition of cutting "excessive" flow lines in the underhead area. Some specifications, such as AS7471, show an example of unacceptable grain flow cutting. This allowance of some cutting is due to the need for underhead removal on bolts in order to have a bearing face close to 90 degrees to the ground shank. To define "excessive" is difficult and possibly needless.

It is standard practice to start with a diameter 0.010 inch over the nominal for most "short" bolts. Due to a swelling of 0.005 inch in the shank, this results in grain flow cutting when the shank is ground to size by the removal of 0.016 inch from the diameter. For longer bolts, such as those with a length ten times the diameter, the cutting becomes more significant. Greater stock must be provided to assure clean up during shank grinding. The starting stock can be up to 0.030 inch over nominal and an additional 0.005 inch increase in diameter can be experienced during forging. The need for more stock removal is due to some materials memory as a coil and also due to some warpage during heat treating. So the prohibition of "too many" flow lines cut would have to differentiate between long bolts and short bolts. All long bolts produced by all the fastener companies for the last 30 years have always had more "flow" lines cut than the amount cut on short bolts.

This prohibition is a costly item for aerospace companies because the bolt suppliers are required to maintain an excess of raw material sizes in order to make the oversize shank parts needed for repair (oversize holes). It is also costly because much time and effort is made trying to bring out flow lines to determine if too many were cut. This determination in a finished IN718 bolt can be a Sisyphean task.

Figure 1 illustrates the type of sketch used to show cut flow lines in bolt heads and show the "flow lines" for bolts in this program. The Aerospace Metals Engineering Committee (AMEC) initiated this program to determine what effect, if any, cutting flow lines would have on aerospace bolts. To assure the maximum cutting of flow lines, this program proposed fabricating the test bolts from bar stock without forging. The proposed program was circulated for comments to individuals and groups including SAE Committee E-25.

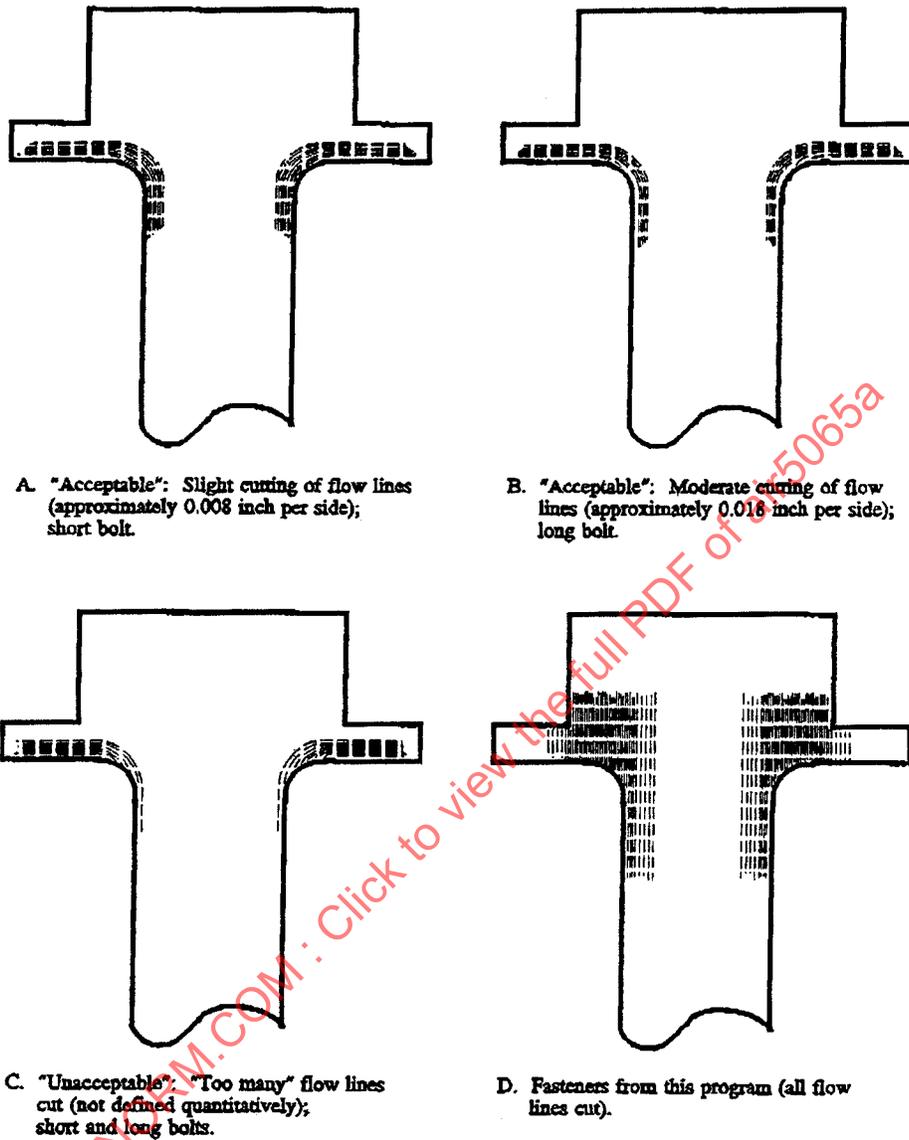


FIGURE 1 - Examples of Flow Line Cutting Due to Grinding of Shank and Underhead Surfaces of Aircraft Quality Bolts

ACKNOWLEDGEMENTS

The following companies made contributions to this program which AMEC gratefully acknowledges.

Federal Mfg. - Chatsworth

Fabrication and testing of 3/8 inch 200 ksi A286

Valley Todeco-Sylmar

Fabrication and testing of 7/16 inch 220 ksi IN718 and Beta C and the testing of 10-32 A286

Bristol-Brea

Fabrication of 10-32 A286

Deutsch-Gardena

Fabrication of 1/2 inch 8740

Automotive Racing Products-Santa Paula

Testing of 1/2 inch 8740

Russell G. Sherman

Coordinator

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1. SCOPE:

Performed tensile and fatigue tests on bolts to determine if cutting of materials flow lines at the bolt underhead would degrade bolt integrity. Five different alloys used in aerospace industry fatigue critical applications were employed to fabricate 5/16 to 1/2 inch diameter bolts. These bolts were machined from bar stock producing fully cut material flow lines under their heads. Tensile testing with and without underhead washers was performed along with industry standard fatigue testing.

2. APPLICABLE DOCUMENTS:

The following publications form a part of this document to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order. In the event of conflict between the text of this document and references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

2.1 SAE Publications:

Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

AS7471 Bolts and Screws, Nickel Alloy, UNS N07001 Tensile Strength 165 ksi, Corrosion and Heat Resistant Procurement Specification

2.2 NAS Standards:

Available from Aerospace Industries Association, 1250 Eye Street NW, Washington, DC 20005.

NAS1348

2.3 Other Publications:

Peterson's Stress Concentration Design Factors, John Wiley & Sons, 1966

3. PROCEDURE:

All the bolts fabricated were machined completely from bar stock to a 12-point configuration. Such a configuration is used by the aerospace industry in fatigue critical applications. The 12 points, of course, were not machined but this area was machined to the minimum of the 12-point diameter. The bolts were then processed in the normal manner, heat treated and then thread rolled and fillet rolled.

The bolts were made, in most cases, with a shank length equal to two times the diameter. This is the shortest part which can properly be fatigue tested. This length also imposes the highest bending stress level to the head and the threads from any misalignment during testing.

Test bolts of the following materials and sizes were fabricated.

TABLE 1

Size	Material	Strength	Part No.	Company
5/16 inch	A286	200 ksi	MS9036	Federal Mfg. Chatsworth
7/16 inch	Beta C	200 ksi	12 pt.	Valley Todeco Sylmar
7/16 inch	IN718	220 ksi	MS14181	Valley Todeco Sylmar
10-32	A286	130 ksi	MS9556	Bristol Mfg. Brea
1/2 inch	8740	180 ksi	MS21250	Deutsch Mfg. Gardena

The tests performed, except for those on 10-32 bolts, were fatigue and tensile tests. Five parts were tensile tested normally and then additional tests were run with a 5-degree washer under the head. The fatigue tests were standard tests at the normal specification loads. If no fatigue failures occurred, the loads were increased to force failure. In addition, the engine bolt configuration A286 10-32 bolts were stress rupture tested. These tests were not stopped at 23 hours but were continued to failure.

Some of the tests were witnessed by AMEC members.

4. RESULTS AND DISCUSSION:

The most significant result was that no parts failed in the head. In many cases the parts were subjected to loads 10 to 20% higher than normal, especially in the fatigue tests. The results are tabulated in Tables 2 through 6.

TABLE 2 - Test Results on MS9036/BACB30LE 200 ksi,
A286 5/16-24 Bolts

Tensile Load Pounds	Tensile UTS, Failure ksi	Fatigue (R=.1) Cycles at Load 5760 lb	Fatigue (R=.1) Cycles at Load 6336 lb ⁽¹⁾	Fatigue (R=.1) Cycles at Load 6912 lb ⁽²⁾
14,350	224 thread	130K nf	130K nf	170K thread
14,340	224 thread	130K nf	130K nf	79K thread
14,125	221 thread	130K nf	6K thread	
2 deg. underhead washer	2 deg. underhead washer	130K nf	44K thread	
14,040	219 thread		100K thread	
14,000	219 thread		94K thread	
5 deg. underhead washer	5 deg. underhead washer			
13,400	209 thread			
13,760	215 thread			
13,740	215 thread			

(1) 10% overload

(2) 20% overload

TABLE 3 - Test Results on MS14181/BACB30US, 220 ksi,
IN718 7/16-20 Bolts

Tensile Load Pounds	Tensile UTS, Failure ksi	Fatigue (R=.1) Cycles at Load 14,700 lb ⁽¹⁾	Fatigue (R=.1) Cycles at Load 16,700 lb ⁽²⁾
2 deg. underhead washer	2 deg. underhead washer	130K nf	51K thread
32,500	252 thread	130K nf	40K thread
32,200	249 thread	130K nf	88K thread
32,500	252 thread	130K nf	107K thread
32,700	253 thread	130K nf	52K thread
5 deg. underhead washer	5 deg. underhead washer		
33,400	259 thread		

(1) 15% overload

(2) 30% overload

TABLE 4 - Test Results on MS9556, 130 ksi A286#10-32 Engine Bolts⁽¹⁾

TABLE 4A

Tensile Load Pounds	Tensile UTS, Failure ksi	Fatigue (R=.1) ⁽²⁾ Cycles at Load 1630 lb	Fatigue (R=.1) ⁽²⁾ Cycles at Load 2000 lb	Fatigue (R=.1) ⁽²⁾ Cycles at Load 2300 lb
3650 ⁽³⁾	162 ⁽¹⁾	130K nf		
3675	163		130K nf	
3705	164			9K thread
3700	164			35K thread
3710	164			45K thread
				44K thread
				34K thread

(1) This part has a reduced shank diameter (pitch diameter). The specification for this bolt calls out the H-28 diameter as the stress area (0.0200) which is considerably smaller than the 0.0226 area (pitch diameter) invoked in NAS1348 and used for this report. The reported tensile strengths of 162/164 ksi would be 190/192 ksi using the smaller area. The larger area was used for consistency with the other bolts tested for this program. The use of different stress areas in various specifications in this country is the source of many troublesome misunderstandings and should be addressed.

(2) This part has no fatigue requirement. 1630 lb represents load for 160 ksi bolt; 2000 lb for 200 ksi; 2300 lb for 220 ksi.

(3) Minimum load per specification 2600 lb.

TABLE 4B

Stress Rupture Test
1200F 1600 lb⁽¹⁾

1. 49 hours broke in shank (pitch dia.)
2. 114 hours broke in thread
3. 35 hours broke in thread
4. 41 hours broke in thread
5. 64 hours broke in thread

(1) Required load per specification is
1260 lb (27% overload).