

Testing of 300 Series Stainless Steel Tubing for Aerospace Applications

Mel Chapman

Plymouth Tube Company

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ABSTRACT

The applicability, interpretation, and implementation of the testing requirements, in various aerospace and military tubing material specifications have caused confusion across the tubing industry. Despite the release of AMS specifications, procurement entities continue to purchase material produced to the older and often cancelled Mil-T specifications. In addition to mechanical properties, these specifications cover requirements including composition, grain size, heat treating, passivation, pressure testing, formability, non-destructive testing, and sampling frequency. Confusion may result for tubing producers who also supply commercial grade tubing having similar mechanical properties aerospace tubing. Ultimately it is the responsibility of the tubing manufacturer to understand the risks involved in meeting the requirements of the aerospace material specifications, both Military and AMS.

INTRODUCTION

There has been a great deal of confusion in the aerospace tubing industry regarding the applicability, interpretation, and implementation of the testing requirements, in various aerospace and military tubing material specifications. This has been evidenced by multiple disclosures within the aerospace tubing industry made by tubing vendors, either on their own or as a result of customer audit indicating a lack of conformance to specified testing requirements and a resultant non-completion of certain test requirements.

The migration of material specifications from Mil-specs to AMS specifications has created confusion into the applicability of specifications requirements when seemingly conflicting specifications are called out on a

single order. This is compounded by the close parallels between the aerospace material specifications (both Mil-T and AMS) and the more commercially oriented ASTM material specifications covering the production of stainless steel tubing.

Within the past few decades, the government, in the form of the Department of Defense, decided to no longer maintain certain military specifications. Since they are still extensively used throughout the aerospace industry, the task of editorial control was picked up by SAE and incorporated into the Aerospace Material Specifications (AMS). AMS specifications exist across the range of 300 series stainless steel alloys.

Despite the release of AMS specifications, procurement entities within the aerospace supply chain continue to purchase under contract material produced to the older and often cancelled Mil-T specifications. This is a result of the requirement that material manufactured as replacement parts for aerospace systems often must be procured to the original design specifications, including those which have been cancelled and superseded.

Along with the mechanical properties (tensile, yield, elongation), the specifications also cover other raw material testing requirements including chemical composition, grain size, heat treating, passivation, pressure testing, formability testing, non-destructive testing, sampling frequency and conformance inspection requirements.

Confusion may result in manufacturing job shops and mills where commercial specifications which produce similar mechanical properties as those required for aerospace tubing are also frequently used. Further complication results from the availability of certain pieces

of test equipment, and building the knowledge base for training competency.

This paper will examine three particular aerospace alloys within the 300 series of stainless steel which are often specified for aerospace tubing applications. I will then discuss the various tests required for several specifications concerning each of these alloys, including any challenges which my organization encountered in implementing the required testing. Finally we will consider the evolution of the various specifications, and where applicable, ancillary reference specifications.

300 SERIES STAINLESS STEEL ALLOYS

GENERAL - Stainless steels are typically classified as belonging to one of five families. The first four (Martensitic, ferritic, austenitic, and duplex) are differentiated by their microstructure. Precipitation-hardenable alloys, the fifth group, are characterized by the type of heat treatment utilized in their processing rather than on the crystalline structure of the alloy.

In terms of available alloys, austenitic stainless steels form the largest grouping among the families of stainless steel. Austenitic alloys are designated under the AISI codes as 200 and 300 series. Hardness of these alloys is not generally affected by the heat treatment in terms of achieving a required physical property, but rather is achieved through some method or successive methods of work hardening, and most typically cold working. These alloys are well known for their ductility and formability over a wide range of temperatures. This paper will focus particularly on alloys 304, 304L, 321, and 347.

CHEMISTRY – Austenitic steels may be separated into the categories of chromium nickel alloys (300 series) and chromium-manganese-nitrogen alloys (200 series). The 300 series alloys are highly dependent upon their compositions of Carbon, Nitrogen and Nickel to maintain their austenitic structure. Corrosion resistance can be regulated with the addition of chromium or molybdenum. As nickel content is decreased, nitrogen can be added to maintain austenitic properties. Nickel composition is directly related to the degree of work hardening of these alloys. Lower Nickel content allows for a significantly higher level of work hardening, and the consequent achievement of higher tensile and yield values, but must be balanced by the addition of manganese to prevent martensitic transformation.

Typical Compositions of 304, 321, and 347 alloys – The following table (Fig 1.) shows the basic chemistries for the three alloys which we utilize for aerospace tubing. By comparison to other alloys in the 300 series, carbon content is maintained relatively low at either a maximum of .03 wt% for 304L and .08 wt% for 304, 321, and 347. Other 300 alloys may contain carbon as high as .25 wt%, although .10 - .15 wt% is common. The carbon content

of these three alloys remains low in large part due to the potential for use in high temperature applications. Nickel content for these alloys could be considered low to mid-range when compared to other austenitics, allowing for suitability for cold working, and the achievement of high tensile and yield strength values.

(Fig 1)

Comp	304	304L	321	347
C	.08	.03	.08	.08
Mn	2.00	2.00	2.00	2.00
Si	1.00	1.00	1.00	1.00
P	.045	.045	.045	.045
S	.03	.03	.03	.03
Cr	18.00-20.00	18.00-20.00	17.00-19.00	17.00-19.00
Ni	8.00-10.5	8.00-12.00	9.00-12.00	9.00-13.00
Mo	....	....	....	....
N	....	....	....	....
Ti	....	....	5 x C	....
Nb	....	....	....	10 x C

Corrosion Resistance of 304, 321, and 347 – The chemical composition of these alloys also plays an integral role in their resistance to intergranular attack. Molybdenum in various amounts can also be added to enhance corrosion resistance. Alloys 321 and 347 are considered to be stabilized grades, due to the inclusion of titanium or niobium. Titanium and niobium act to stabilize carbon during exposure to elevated temperatures and to prevent the precipitation of carbides along the microstructural grain boundaries during high temperature conditions. Alloys such as 304L have been created to mitigate the possibility of intergranular attack through the intentional limitation of carbon in the alloy. Verification of the absence of intergranular attack following processing of the tubing material is performed both metallographically and chemically and will be discussed later.

MECHANICAL PROPERTIES – Tensile and yield values are relatively constant across the range of aerospace specifications in which 304, 304L, 321, and 347 are utilized. Test values depend upon the tubes nominal outside diameter (OD) and nominal wall thickness, and usually assume that the tube is in the fully annealed condition. Some conditions do exist where the tubing is required to be in a hardened state, (i.e. un-annealed) where 304 or 304L alloy is predominantly used. Figure 2 shows the typical mechanical properties for these alloys.

Fig 2.

Condition	Ultimate Tensile (ksi)	Yield Strength (ksi)	Elongation (2 inches %)
½ Hard	150	110	7
1/4 th Hard	120	75	12-15
1/8 th Hard	105 - 140	75 – 110	20
Fully Annealed	75 - 115	30	35 - 40

OTHER SELECTION FACTORS – In addition to mechanical properties, selection of stainless steels for tubing applications may also be based upon the follow the some of the following factors;

- Corrosion resistance (normal temp and high temp) during service.
- Strength and ductility during post tube production forming and in service use.
- Structural property stability in service
- Susceptibility to corrosion in localized areas such as weld joints.

The selection of alloys becomes apparent in the titles of the aerospace specifications which often reveal the potential service environment. Cross reference to the various specification titles used in this paper may be found in the reference section of this document.

TESTING OF AEROSPACE TUBING

GENERAL – The testing of tubing is divided between acceptance testing and periodic testing, and performed on a lot by lot basis. Typically, a lot is defined as one size and wall thickness of tubing annealed in the same charge (in the case of batch annealing), or all tubing of

one size and heat annealed at the furnace same control temperature, atmosphere, and time without interruption (in a continuous furnace).

Additional testing may be required indirectly by referenced specifications. Details of these test requirements might not be expanded upon in the particular production specification. In such cases where only a reference is made to an ancillary specification, it is prudent for the material producer to obtain the additional specifications which are referenced in the product specification, and determine whether or not the current manufacturing process can also meet the requirements of the ancillary specification.

For example;

Mil-T-6845D “Tubing, Steel, Corrosion Resistant (S30400), Aerospace Vehicle Hydraulic System 1/8 Hard Condition” in Section 2, Applicable Documents, makes reference to the following additional specifications which become a part of Mil-T-6845D to the extent described in Mil-T-6845D;

- QQ-P-35 “Passivation Treatments for Corrosion Resistant Steel”
- MIL-H-6875 “Heat Treatment of Steels”
- MIL-STD-753 “ Corrosion Resistant Steel Parts: Sampling, Inspection
- AMS-2243 “ Tolerances – Corrosion and Heat Resistant Steel Tubing”
- ANSI-B46.1 “Determining Average Grain Size”
- ASTM A 370 “Mechanical Testing of Steel Products”

Of special note, the first 3 items listed above are considered cancelled and have been superseded, but are still regularly referred to in the procurement of stainless steel tubing for aerospace and defense applications.

The aerospace product specification may establish an order of precedence for the applicability of requirements when additional specifications such as those noted here are called out. In most cases, the highest level product specification will take precedence unless otherwise dictated in the contract document issued by the customer.

CHEMICAL COMPOSITION – Each product specification typically specifies chemical composition limits for the alloy(s) approved for use in the production of tubing to that specification. Special care must be taken by the tubing producer when multiple specifications are referenced on a contracting document. While certain specifications which allow the use of a particular alloy