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An Experimental Investigation on Thread-Connection Strength of an Al-Li Alloy Forging

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Abstract

To reduce structure weight by using Al-Li alloy as a substitute for conventional aluminum alloy, thread-connection strength of a 1420 forging was investigated through tensile tests, as a function of thread size, thread depth and orientation of the female screw samples. The main results are as follows: (1) Failure loads of M4 type of screw samples are quite scattered, no matter how many circles of threads were involved. (2) Repeatable failure loads were detected for samples with M5 to M10 type of screws. (3) A linear increment of connection-strength with increasing thread circles was detected for a given type of screw samples, and the bigger the thread size, the greater the increasing rate. (4) Higher strength was detected for samples cut along longitudinal direction of the forging than for samples along its radial direction. Discussions and suggestions were given based on the above results.

1. Introduction

Li-containing aluminum alloys are quite attractive in the manufacture of light weight structures of aircrafts or space flight vehicles, due to their high specific strength, high specific modulus and acceptable weldability [1-4]. It is also sometimes necessary to use Li-containing aluminum alloys as a substitute for traditional aluminum alloys in the manufacture of components connected by threads. In such cases, cautions must be taken in choosing threads, because of the sensitivity of Li-containing aluminum alloys to stress concentrations [5] caused by machining notches and scratches at the root region of thread teeth. In addition, the effect of machining damage on load-bearing capacity is also unclear. For purpose of collecting information for making components connected with threads, attempt was made in this paper to investigate thread-connection strength of a 1420 forging as a function of its thread size, thread depth and orientation of thread-connection.

2. Experimental Procedures

Samples containing M4, M5, M6, M8 and M10 type of standard female screws (see Figure.1) were machined from the 1420 alloy forging, with their axes parallel to the longitudinal and radial directions of the forging, respectively. The male screws used to match the female screw samples were machined from a 30CrMnSi steel tempered as commonly used in the industry, with a hardness of HRC=37.

The nominal composition of the 1420 alloy was identified to be Al-5.0Mg-2.0Li-0.1Zr in weight percent, plus a minute amount of rare earths. The mechanical and physical properties of the forging are listed in Table 1.

Table 1 Mechanical and physical properties of the 1420 forging

Direction	$\sigma_{0.2}$,MPa	σ_b,MPa	Elongation,%	E,GPa	Density,g/cm^3
Longitudinal	261	403	8.6	76	2.47
Radial	249	333	3.5	76	2.47

Thread-connection strength of the 1420 alloy samples were measured with a ZDM-10 testing machine. As is shown in Figure.2, a strain gauge was used to detect the deformation behavior of the threads tested, an X-Y recorder was used to record the load-deformation displacement curves of the samples. The maximum load on such a curve is defined as the failure load of the corresponding sample. For a given type of screw samples tested at the same depth, an average of four failure loads is defined as its thread-connection strength. In preparation of the tests, special attention was paid to the design of specimen attachments, in order to keep the sample axis in alignment with the tensile direction of the testing machine and to ensure a group of samples to be tested at the same depth. For the convenience of comparison, thread-connection strength of a 6061 alloy forging was also measured under the same testing conditions.

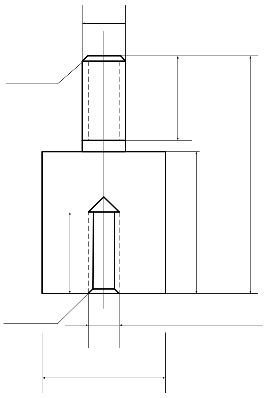

Figure 1: The shape and dimensions of the female threads to be tested.

Figure 2: Picture showing the layout of specimen attachments.

3. Results and Discussions

Typical load-deformation curves of the tested samples are shown in Figure.3. It is clear that the load of the threads tested increases linearly with deformation soon after loading begins. As the load approaches its maximum, small deviations from linearity appears, suggesting that some extent of plastic deformation occurred before failure. In addition to a relatively lower strength, the 1420 alloy exhibited a relatively poor ductility, suggesting that its threads would be more “brittle” than those of the traditional 6061 alloy.

When the load reached its maximum, all of the samples of 1420 alloy failed suddenly in a “shear-off” failure mode at the root region of the tested threads, see Figure.4.

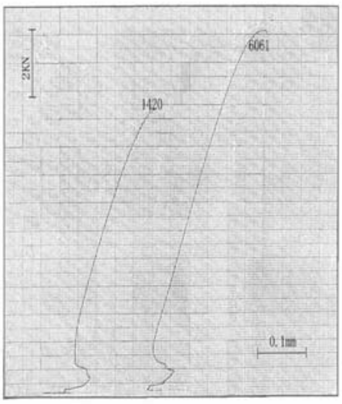

Figure 3: Typical load-deformation curves of M6 type screw samples tested at 5 circles.

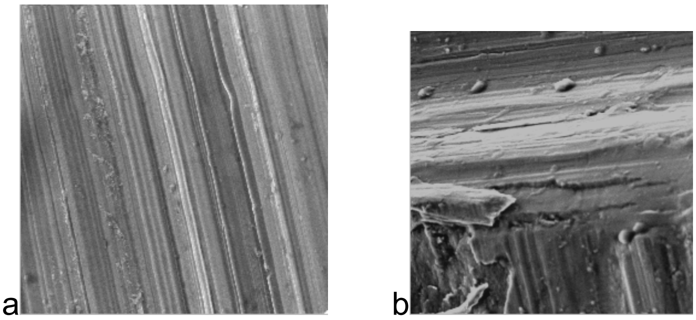

Figure 4: SEM micrographs showing (a) appearance of the shear-off fracture surface, and (b) the root region, of a failed thread of 1420 forging.

For the samples of both alloys with M4 type of screws, data of the failure loads are quite scattered (see Table 2), especially for the 1420 samples, suggesting that the load –bearing capacity of smaller threads are seriously affected by machining damages.

Table 2: Failure loads of M4 type screw samples with 5 circles of threads (kN).

Alloy	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
1420	0.30	1.56	0.27	0.21	1.18
6061	1.42	2.25	2.00	2.95	3.33

For the samples with M5 type of screws or bigger ones, data of the failure loads exhibited a good repeatability (see Table 3), suggesting that the effect of machining damage on load-bearing capacity of M5 type screws and bigger ones can be neglected.

Table 3: Failure loads of 1420 alloy samples with 5 circles of threads (kN).

Screw type	Sample 1	Sample 2	Sample 3	Sample 4
M5	8.53	8.33	7.85	8.33
M6	12.94	12.10	12.15	12.41

The measured relationships between thread-connection strength and thread depth (i.e. circles) for all of the 1420 alloy samples are shown in Figure.5. It was found that: (1) With the thread depth tested increases from 4 to 8 circles, the connection strength of 1420 alloy exhibited a linear growth, and the bigger the screw size, the greater the increasing rate. (2) For samples tested at the same thread circles (but different depth), the connection strength of M10 type of screws is nearly 4 times of that of M5 ones.

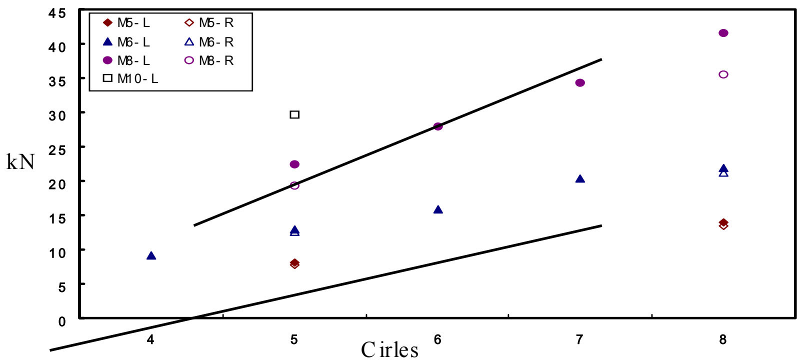

Figure 5: Experimental relationships between thread-connection strength and thread circles of 1420 alloy samples. L – longitudinal, R – radial

(3) For the same type of screws tested at the same circles of threads, samples cut along longitudinal direction of the forging exhibit a higher connection strength than those cut along the radial direction, especially for bigger size threads, suggesting that an anisotropy of thread-connection strength exists. (4) When the M5-M8 types of screws were tested at a greater depth than 8 circles, it was the tempered 30CrMnSi male screw, rather than the tested threads, first failed by appreciable plastic deformation or necking, suggesting that more circles of threads are not necessary in actual thread-connection operation.

According to the design manual of manufacture [6], the strength condition of a screw against shear-off failure of its threads should be

$$\tau = F/0.58\pi dns \leq \tau_b \quad (1)$$

where, τ is the shear stress, F is the axial load, d is the radius of the screw, n is the circles of the threads, s is the distance between neighboring thread teeth, τ_b (=σ_b /2) is the shear strength of the material. Using the above relation and the measured ultimate tensile stress σ_b of the material, the maximum theoretical load for the screw to bear safely can be estimated with the following expression

$$F_t = 0.58\pi dns\tau_b \quad (2)$$

The estimated results for samples cut along longitudinal direction of the 1420 forging are listed in Table 4, together with the measured strength in brackets.

Table 4 The maximum theoretical loads of 1420 screw samples estimated (kN)

Screw type	5-circles	6-circles	7-circles	8-circles
M6	11.64 (12.90)	13.97 (15.91)	16.30(20.32)	18.63(21.83)
M8	19.40(22.41)	23.29 (27.98)	27.12(34.35)	31.05(41.52)

Three points are quite clear from Table 4:

(1) All the maximum theoretical loads are relatively lower than corresponding experimental results.
(2) The bigger the screw size, the greater the differences.
(3) For a given type of screw, the more circles of threads are involved, the greater the differences.

These phenomena suggest that, in addition to stress concentrations originated from machining notches and scratches, there must be a certain extent of notch-strengthening effect [7] occurred in the root region of a thread.

When the screw size is big enough (i.e. when the machining damage is negligible), the notch-strengthening effect would be great enough to overwhelm the stress concentration sensitivity, leading to a stable and greater strength than the estimated.

As a net result of the interaction of notch-strengthening with sensitivity to stress concentration, it seems that the bigger the screw size or the more threads are involved, the safer it would be when designed according to the common method, and vice versa.

When the screw size is too small like in the case of M4 type samples, where the effect of machining damage on load-bearing capacity cannot be neglected, the common design method fails to give a safe prediction of the failure loads as indicated by Table 2. The details of this damage effect need to be further investigated.

4. Concluding Remarks

For the 1420 alloy forging investigated in the present study, its components can be thread-connected by M5 type or bigger size of screws designed through the common method. In the cases of matching with tempered 30CrMnSi male screws, more than 8 circles of threads are not necessary. Attempts of connecting 1420 components with M4 type of threads or smaller ones are unacceptable.

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