Thin Wall AW3103 Pipe – Dynamic Load Concerns

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Abstract. Surveys from all over the automotive industry are showing an increase in the usage of aluminium year after year. Compressed air systems are part of a modern car’s assembly and are constantly under load from vibrations. Because of this, the life span of the material (product) is significantly shortened. Throughout this paper we will present a series of tests and results, which shed some light on the viability of aluminium pipes in dynamic conditions. These tests were made on raw and custom shaped samples, to study the effects of form and tempering.

1. Introduction
In the last few years, there has been an increase in aluminium usage among automobile manufacturers. As predicted, due to its fairly good mechanical properties and 100% recyclability, aluminium remains “the fastest growing automotive material over competing materials and is entering its most unprecedented growth phase”[1].

The European automotive industry is considered technically the most advanced and highly innovative [2]. Because of political pressure to reduce fuel consumption and CO₂ emissions, the efforts for automotive companies to reduce total mass has shifted from using steel to lightweight materials, one solutions being aluminium alloys. During the last decade the average amount of aluminium used in cars has doubled, and based on this trend, its usage will keep growing.

In recent years, aluminium piping has become a solid alternative to other piping materials for compressed air systems. Conventional compressed air systems equipped with moisture trap will still have some moisture in the system and corrosion will occur. Additionally, loose scale deposits collect over time and create pressure drops.

Also, aluminium’s high thermal conductivity maximises heat transfer in applications such as heat exchangers. Thanks to its low cost and easy formability into complex shapes, aluminium is increasingly utilised in these applications. Heat exchangers also take advantage of aluminium’s: high strength, low density and corresponding light weight, machinability, mechanical strength and shape retention after machining.

Aluminium alloy EN AW-3103 or AA 3003 is a good candidate for extruded round tubes because of its long life. It is primarily used in various types of ‘mechanical expanded’ type heat exchangers (condensers and evaporators). AW3103 is manganese alloy with a high corrosion resistance. The alloy has an average strength and is suitable for welding and bending.

2. Static load premises
Thin walled AW3103 aluminium pipe has been brought to our attention due to its erratic act in live conditions. Pipes of various shapes and sizes had the same symptoms.
The two main types of tubes were sorted into: inner diameter (i.d.) 9.5 mm – outer diameter (o.d.) 12 mm and i.d. 15 mm – o.d. 18 mm (Figure 1). In order to assess their dynamic response, some static tests were performed to acquire their elastic modulus.

Using a universal tensile testing machine, the specimens were subjected to a controlled tension until failure. This way we directly measured ultimate tensile strength, breaking strength, maximum elongation determining Young's modulus. Considering the number of specimens tested, 18-24 elements, the results (Table 1) were pretty inconsistent and sparse thus raising first questions about the material [3, 4].

### Table 1. Extreme and average values for test specimens

| Parameters | i.d.9.5 mm – o.d. 12 mm | i.d.15 mm – o.d. 18 mm |
|------------|-------------------------|-----------------------|
|            | min | max | avg | min | max | avg |
| E [N/mm²]  | 38375 | 67575 | 65132 | 17964 | 73248 | 63080 |
| Fm [kN]    | 0.73 | 5.21 | 5 | 8.39 | 15.53 | 11 |
| Rp0.1 [N/mm²] | 11.96 | 104.66 | 99 | 72.56 | 105.62 | 97 |
| Rp0.2 [N/mm²] | 12.61 | 109.93 | 104 | 87.73 | 109.75 | 99 |
| Rm [N/mm²] | 17.02 | 121.31 | 114 | 108.89 | 204.568 | 123 |

In order to be able to plot a fatigue (Wohler) curve, we needed stress values for the pipes (Figure 2), and with the aid of previously determined elastic modulus we did a comparison of strain resulted from load cell and stress resulted from strain gauges applied on the pipes in the elastic region.

![Figure 1. Untested 9.5-12 mm tubes and tested 15-18 mm tubes](image1)

![Figure 2. Stress comparison of average values for 6 specimens (i.d 15 mm – o.d. 18 mm)](image2)
The test specimen was precisely tensioned by a high precision stepper motor (1/1440 mm) and the stress was measured with both through strain gauges attached on the specimen and load cell attached to the tensioning cable (Figure 3).

![Stress validation set-up](image)

Figure 3. Stress validation set-up

3. Dynamic load testing
Having an idea about the stress values at different amplitudes / displacements, we pursued to test the life limit of the two type of tube in two separate architectures. The fatigue experiments have been carried out with custom specimen arrangements depending on the diameter of the tubes.

3.1. Forced vibration at resonance
For the i.d.9.5 – o.d.12 mm pipes there was a special curvature requested, and the specimens were oscillated at resonance (around 37-38Hz) with discrete acceleration on an electrodynamic shaker in order to maintain a specific displacement/strain, ergo stress.

On a group of 18 test specimens vibrated till fracture, there was again a considerable gap between the numbers of cycles for a specific stress value (Figure 4). The values for the Y-axis was specifically omitted not to be in breach of contract. Overall, the fatigue curve of the tested pipes do resemble the AW3103 Wohler curve, but a little bit reduced in number of cycles. Throughout the fatigue test, for different accelerations, a specific strain was maintained with the aid of inductive sensors which monitored the maximum displacement of the pipe’s free end. The setup rig for this scenario is shown in Figure 5.

Special care was needed to monitor the acceleration on all 3 axes due to the peculiar nature of the test: the grips needed to be sturdy enough not to overdamp the specimen’s vibration and at the same time, due to resonance the acceleration on all 3 axes would act out due to the mass grips and its center of gravity. During these test Bruel&Kjaer Type 4506 and 4513 micro accelerometers were used and they were harshly taxed for hundreds of hours at acceleration exceeding even 160 m/s².
Although the pipes were machined formed and basically had the same form, curvature and mass, their initial resonance frequency was not the same, indicating a difference in them, and this frequency decreased inversely proportional with the duration of the tests.

![Graph showing sparse values for stresses based on number of cycles](image)

**Figure 4.** Sparse values for stresses based on number of cycles

![Image of ED shaker with pipe for resonance fatigue set-up, static and during resonance](image)

**Figure 5.** ED shaker with pipe for resonance fatigue set-up, static and during resonance
3.2. Forced vibration at constant displacement
For the i.d.15 mm – o.d.18 mm pipes there was a different test setup, and the specimens were mechanically oscillated with aid of a specially developed crank and connecting rod mechanism able to obtain and maintain symmetric displacements between 0.4 and 2 mm. Several attempts were made to achieve and control this small displacement, and the final version is the one presented in Figure 6.

![Test specimen and variable displacement mechanism](image)

**Figure 6.** 0.4mm symmetrical displacement

On a number of 12 test specimens ruptured so far, there is a significant gap between values on the Wohler curve. Again, in order to avoid breach of contract, values for the stresses have been omitted (Figure 7).

![Stress values graph](image)

**Figure 7.** Sparse values for stresses based on number of cycles
These tubes, had connection couplings welded at their end and one may mitigate that this procedure would act as tempering. None the less, the welding procedure is an automated one, so this would affect all the specimens the same way. From the previous data obtained from static tests, there wasn’t a specific convergence in values.

From the same material, with same dimensions, there were three type of coupling attachment methods: laser welding, tinning and snug fit. Although there is obvious variations between the life cycles of these assemblies, they all show a common treat, in the way that there is no specific point of convergence for a specific value of stress as a function of number of cycles.

4. Conclusion and results
The goal of this paper is to point out the premature failure in AW3103 tubes that are used in the automotive industry, caused by material flaws, mainly due to material heterogeneity. To this end, several samples from two types of tubes of same material where tested statically to determine their elastic modulus and dynamically to determine their life cycle.

From a statics point of view they failed due to the lack of a common convergence point or a narrow dispersion range for the elastic module.

From a dynamics point of view their “stress-number of cycles” curves did not present the same converging point for each stress value, but rather a pretty wide range.

Based on these findings and the specifics of the tests performed we can rule out automated mechanical forming of the tubes as a main cause for premature failure of finite products made from AW3103 and suggest looking into the quality of the raw material from which these tubes are made or their handling before machining (previous/multiple plastic deformation).

Although the geometry of the first type of tubes, i.d.9.5 - o.d.12 mm, would clearly make them fracture at the base of the fixture, during the fatigue tests there was a case in which one of the tubes cracked in a bended area where the stress values were lower (Figure 8), once again proving material problems and early onset of fracture!

![Figure 8. Double crack in bended area during fatigue testing](image)

5. References
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