



DESIGN, FABRICATION AND ECONOMY OF WELDED STRUCTURES

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6.3 Numerical Simulation of Buckling of Metal Tubes

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Abstract

This article deals with the deformation specialities of aluminium circular tubes. These tubes could be used to absorb energy of collisions. For example in a test rig created to measure and test seat belts a batch of tubes slow down the test rig and simulate the deformation of a car chassis. Circular tubes with the same cross section and tube length parameters made of three different aluminium magnesium alloys were analysed by finite element method to determine the effect of increasing yield strength values on energy absorbed.

Keywords: aluminium, buckling, finite element method

1 Introduction

In case of metal structures built for the automotive industry it is a must to design reliable and cheap parts and assemblies. Besides there is also a strong need to have lighter and safer car bodies. Saving weight and increasing safety by designing more rigid car bodies could be tough challenges, but even those two requirements can be built into one structure by using light metals like aluminium.

Passenger safety can be increased in the case of a car built with an aluminium space frame – like the one that can be seen on Figure 1 – for example with energy absorber elements. Those elements absorb collision energy by deformation. Their form, cross section can be different, some elements can even have buckling initiators to guide the deformation. Such a buckling initiator can be seen on Figure 2. This absorbing element is an aluminium rectangular hollow section with 50mm flange width and 100mm web height.

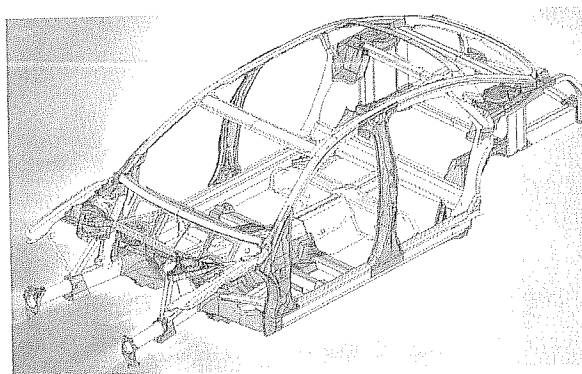


Figure 1.
Aluminium space frame

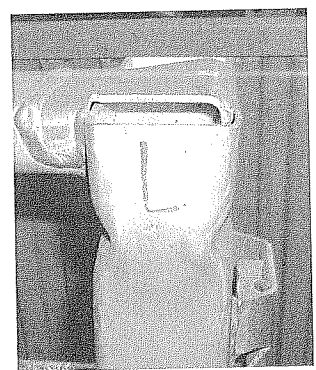


Figure 2.
Energy absorbing element
with buckling initiators

To determine the dimensions of such aluminium profiles and to choose the best suitable alloy for the purpose a finite element analysis is required.

This article deals with the deformation specialities of an aluminium circular tube that can be used as an energy absorber at the front of a car space frame. Finite element method is used to analyze the deformation of this axially compressed aluminium tube to figure out how the geometry and material properties affect the way of deformation.

2 Tube geometry

To find the initial values of the tube cross section parameters for the FEA we relied on the numerous references written on axially compressed tubes. Andrews et al. (1983) determined the deformation modes of axially compressed circular aluminium tubes based on quasi-static experiments. In their article a table was published that contained the different deformation modes in the function of L/D (tube length / inner diameter of the tube) and t/D (thickness / inner diameter of the tube).

Seven different deformation modes were derived from the experiments: a) concertina, b) diamond, c) Euler-type, d) concertina and 2 and/or 3-lobe diamond, e) concertina and axisymmetric crushing, f) 2-lobe diamond, g) crushing plus tilting of tube axis.

From the seven types only two of them are considered important in the frame of energy absorption: a) concertina shown on Figure 3.a and b) diamond shown on Figure 3.b. Andrews et al. stated that concertina mode absorbs the highest amount of energy per unit length of tube, so in our finite element analysis we would like to receive only this type of deformation.

The table Andrews et al. published contained the seven modes as a map (see Figure 4), where one can find the predictable tube deformations based on L/D and t/D ratios.



Figure 3a. Concertina type of deformation



Figure 3b. 3-lobe diamond type of deformation

As the table of Fig. 4. shows the concertina deformation mode can approximately be restricted to the area of $0.5 < L/D < 5$ and $0.02 < t/D < 0.1$ where D is the inner diameter of the tube, t is the thickness of the tube, L is the initial length of the tube.

Abramovitz et al. (1997) made detailed experiments with quasi-static and dynamic loads. Referencing their work and based on numerical simulations N.K. Gupta (2000) states in his article that D/t should be between 70 and 90 to receive a concertina mode for deformation. Above that area diamond deformation mode can be predicted.

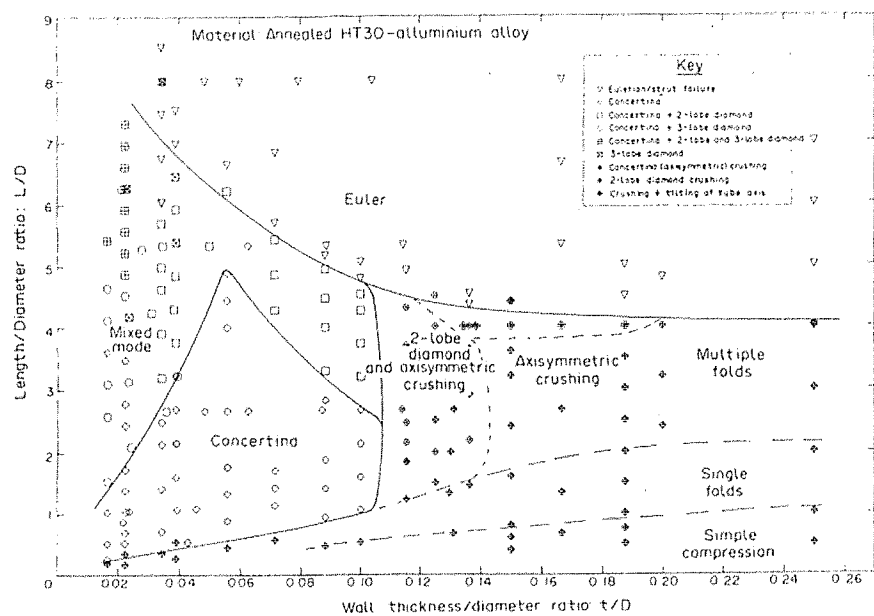


Figure 4. Deformation modes of aluminium tubes created by Andrews et al.

To set the dimensions of the tube cross section the catalogue of standard sections of ALCOA Extrusions was used. The values were chosen from the "middle" of the section table in order to preserve the possibility of both decreasing and increasing the value of the parameters. Supposing that the initial length of the tube is $L=250\text{mm}$, the initial values of the cross section parameters are shown in Table 1.

Table 1. Cross section parameters for finite element analysis

D' [mm]	t [mm]	L/D	t/D
90	4	3.048	0.048

where D' is the outer diameter of the tube.

3 Aluminium alloys

The aluminium – magnesium alloys are widely used in automotive, marine applications since they can be manufactured easily in cold state and they are

weldable. With heat treatment their mechanical properties can be significantly improved. From those alloys three were selected for our purposes.

Table 2. Properties of aluminium alloys used for the analysis

<i>Alloy</i>	<i>State</i>	$R_{p0.2}$ [MPa]	R_m [Mpa]	A_5 [%]	E [MPa]	ν
6060	T1	65	130	15	69500	0.33
6082	T4	110	205	14	70000	0.33
6060	T5	150	190	10	69500	0.33

The finite element analysis had to be made with the same geometry for all aluminium alloys in order to determine the best alloy suitable for energy absorber elements.

4 Analysis

For the quasi-static analysis MSC.PATRAN pre- and post processor and the explicit finite element solver MSC.Dytran were used.

The middle surface of the 250mm high tube was modelled and 50 nodes both on the circumference and length of the tube were defined. Quadratic shell elements were created based on the nodes. To compress the tube two rigid surfaces were also defined at both ends of the tube. One of the rigid surfaces was fixed, the other (we can refer to it as "ram") was moved downwards (in $-z$ direction) 125mm parallel with the axis of the tube. At the fixed end the translational degrees of freedom of the nodes were fixed, the rotation was allowed for both ends.

With defining such a loading condition it is possible to explore the elastic and plastic strain energies while compressing the tube. The software is capable of calculating both of those energies so the energy absorption of such an element can be analysed.

Aluminium was defined as an isotropic material with two constitutive models:

1. Elastic: defined with elastic modulus and Poisson's ratio.
2. Plastic: with elastic-plastic type, with isotropic hardening rule and von Mises yield criterion. The strain rate method was set to piecewise linear.

The elements are expected to touch both the rigid end surfaces and each other so contact was also incorporated into the finite element model.

5 Results

The results of the simulations are in good correlation with the results of the experiments and theoretical investigations that can be found in the references.

The special barrelling that is described by Singace A.A. (1999) can be experienced near the two rigid end plates as it is shown on Figure 5a. Figure 5b and 5c. show the deformed shape of the tube that were reached later in the simulation.

MSC.Dytran is capable of listing several simulation parameters and calculated results. The diagram below shows the energy of distortion expressed in Joule. It can be seen that an alloy with higher yield strength requires higher energy levels to reach the same level of distortion. It can be said that it is recommended to use an alloy

with higher yield strength for the same tube length because more energy can be absorbed on unit length.

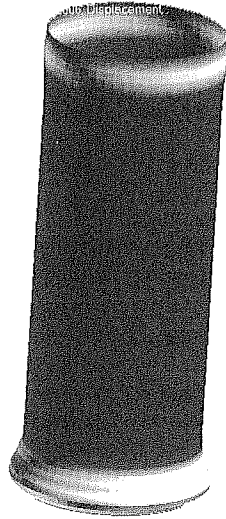


Figure 5.a Barrelling at both ends

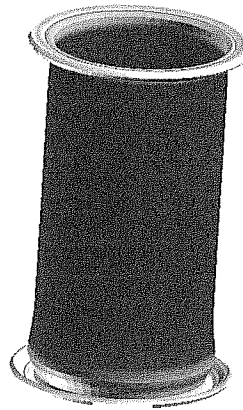


Figure 5.b Development of bends in concertina mode

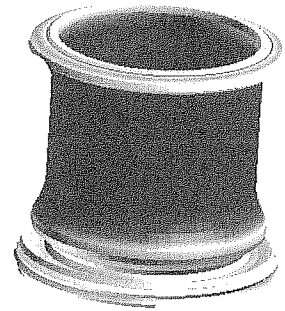


Figure 5.c Development of bends later in the analysis

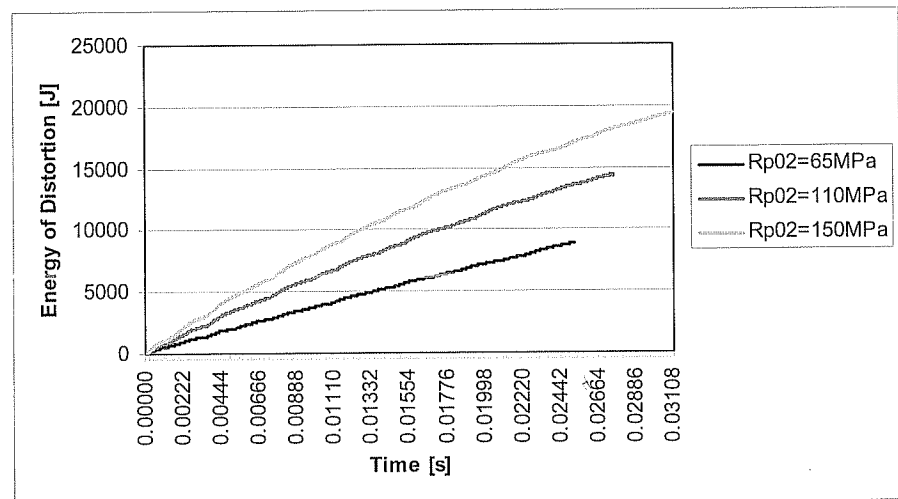


Figure 6. Values of energy of distortion

On Figure 7 the deceleration values calculated on the moving ram can be seen.

From the graphs of decelerations we can derive that the higher the yield strength is the bigger the deceleration of the ram will be. The periodic shape of the graphs came from the periodic way of deformation: when the material collapses and one ring of

the deformed tube reaches the ring before, the deceleration values rise and drop the same way.

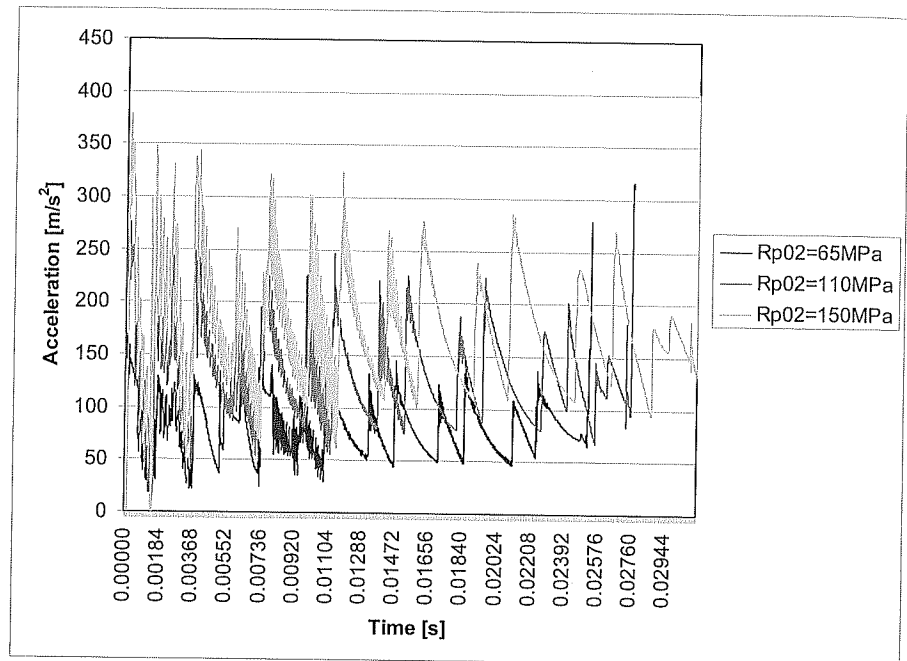


Figure 7. Decelerations of the ram

6 Conclusions

With the help of quasi-static numerical simulations the deformations of aluminium cylindrical tubes were examined. It was shown based on analyses with different yield strengths that the tube made of an alloy with higher yield strength can absorb more energy per unit length than a tube with smaller yield strength value. Therefore, it is recommended to use high-strength aluminium for the shock absorber elements of vehicle frames.

7 References

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