NUMERICAL SIMULATION STUDY ON THE RING FRAGMENTATION

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Abstract: *Ring fragmentation and by extension shell fragmentation is a complex dynamic phenomenon extensively studied starting with the beginning of the 20th century. While mathematical models provided by previous researches fairly describe the real phenomenon, a numerical simulation approach can also be considered as a useful tool in detailing some aspects of fragmentation. The present paper is aimed at investigating several possible approaches for ring fragmentation numerical simulation using two commercial available FEM software pieces namely Autodyn and LsDyna. The results indicate that using LsDyna software along with a Weibull distribution of failure strain ensures a higher value for the residual ring mass.*

Keywords: *ring, fragmentation, Autodyn, LsDyna.*

1. Introduction

In the high explosives detonation phenomena gases are generated up to 300 kbar, at about 3,000 - 4,000°C. These hot gases expand and most of the energy released forms a layer of compressed air (blast wave) in front of this gas volume [Ngo, 2007]. When the explosive is enveloped in a metallic enclosure, the energy is transferred to the enveloping material, leading to fragmentation and high-velocity shrapnel.

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Basically, the fragmentation of hollow metal shells or rings subjected to rapid expansion by impulsive internal pressure is a dynamic process that can be split in several stages. Firstly, shell or ring wall is driven and compressed by shock wave and gases and undergoes elastic deformations. Once the flow stress threshold is exceeded, at the internal face, the plastic deformation starts and the area affected is expanded towards the outer wall. Having a radial displacement the shell continuously increases its diameter. That will lead in the end to a level of circumferential strain and correspondent stress for which the shell material fails and breaks. These cracks evolve from outside of the shell toward interior. Simultaneously, the micro-flaws will generate cracks at the interior face level that propagate toward exterior surface at a 45° angle. When these two types of cracks are joining or pass through all thickness of wall, the fragments are generated. The compressed gases flow through the opens and continue to accelerate the fragments till the maximum value.

The fragmentation phenomenon was thoroughly investigated by several researchers like Rosin and Rammler (1933), Lineau (1936),Weibull (1939), Schuhmann (1941), N.F.Mott (1943 and 1947), Gilvary (1961), Shockey (1974), Grady (2007) and others [Levy, 2010]. From the previous mentioned, N.F.Mott (statistical and physical based model) and Grady (energy based model) stand out due to their large scale used models regarding fragmentation phenomenon.

Along with FEM software's development an alternative way to investigate natural fragmentation emerged. The biggest advantage of using such an approach is that different failure conditions can be used. Thus, starting from the simplest failure condition (constant failure strain) to complex conditions accounting for strain rate, triaxiality and Lode angle can be considered.

The aim of the present study is to investigate several approaches for ring fragmentation numerical simulation available in Autodyn and LsDyna commercial software. The results provided by these numerical simulations were compared in terms of residual mass and number of fragments with an emphasis to strain fringe pattern.

2. Ring Fragmentation Numeric Simulation

2.1 LsDyna Case

Since LsDyna commercial software is a general purpose finite element program no specific capabilities for ring or shell fragmentation is available.

However, since the software is extremely versatile, it can be easily used to solve problems pertaining to the military field of interest.

For the current study a fully 3D approach was adopted and a 0.1mm value (one element) was assigned to the ring high. For the ring inner radius and thickness a 10mm respectively 4mm value was adopted. Once the geometry had been completed a mesh of 0.1mm was considered for the simulation. The 0.1mm value for element size was chosen based on the balance between residual mass conservation and reasonable computational resources needed. For the explosive and air a mesh gradually increased from 0.2mm to 0.8mm was considered. As a result, 36300 elements were generated (***Figure 1 and Figure 2***).

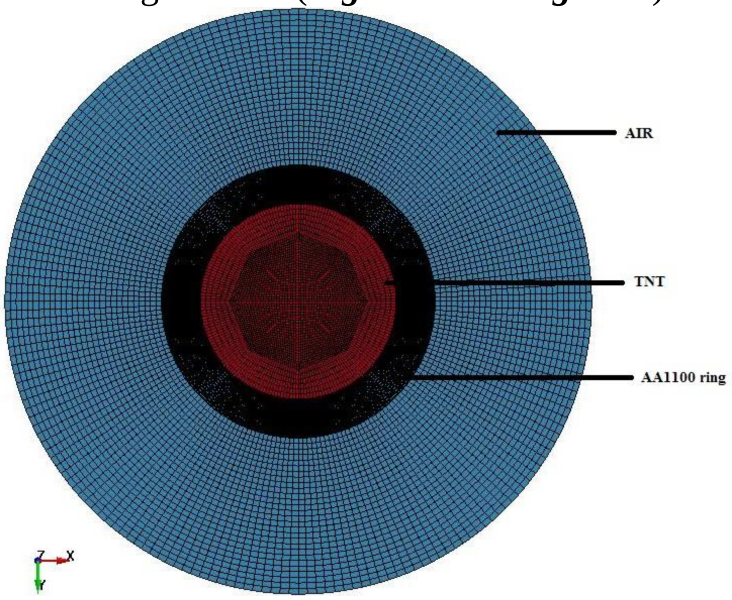


Figure 1. *Model mesh*

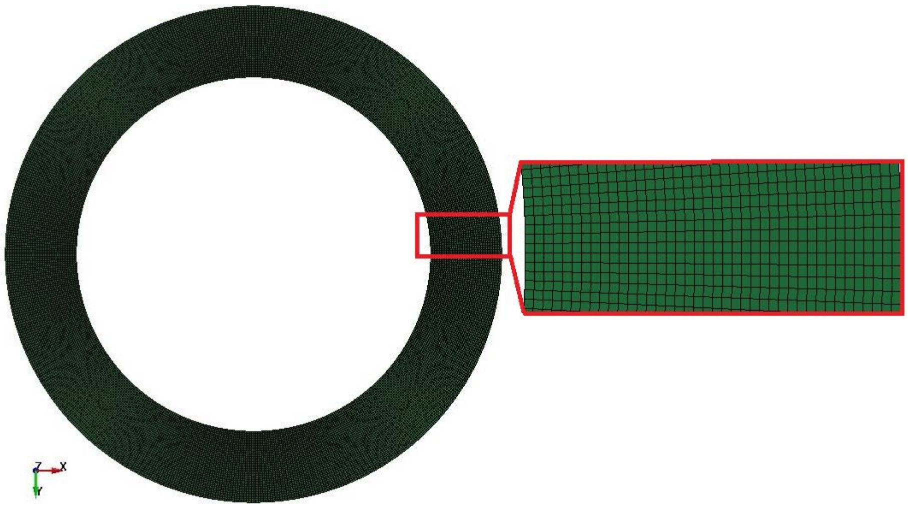


Figure 2. *Ring mesh*

According to LsDyna modeling guide lines a Constrained Lagrange in Solid approach was adopted in order to simulate the fluid-structure interaction.

The explosive used in simulation was the TNT and for the surrounding the constitutive model for Air was defined. A Lagrange formulation for aluminum ring (element type 1) and multi-material ALE formulation (element type 11) for TNT and AIR was adopted. The data used in simulation for EOS, strength model and erosion criteria are summarized in **Table 1**.

Table 1.
Material data (LsDyna unit: T, mm, s, N, MPa)

Property	AIR	TNT	AA1100-O
EOS JWL			
A	-	3.71e+5	-
B	-	3230	-
R1	-	4.150	-
R2	-	0.950	-
Omeg	-	0.300	-
E0	-	4300	-
V0	-	1	-
EOS LINEAR_POLYNOMIAL			
C0…C3, C6	0	-	-
C4, C5	0.400	-	-
E0	0.258	-	-
V01	1	-	-
MAT_HIGH_EXPLOSIVE_BURN			
RO	-	1.630e-9	-
D	-	6.930e+6	-
P_{CJ}	-	2100	-
MAT_NULL			
RO	1.23e-12	-	-
MAT_STEINBERG			
RO	-	-	2.710e-9
G0	-	-	27100
SIG0	-	-	40
BETA	-	-	400
N	-	-	0.270
SIGM	-	-	480
B	-	-	6.520e-5
BP	-	-	6.520e-5
H	-	-	6.159e-4
TM0	-	-	1493
GAM0	-	-	1.970
SA	-	-	1.500
EROSION CRITERIA			
EFFPS	-	-	1

The results obtained through this approach lead to 98 fragments and a residual mass of 62.689% of the initial mass. Details regarding final fragmentation and intermediate strain fringe are plotted in ***Figure 3*** and ***Figure 4***.

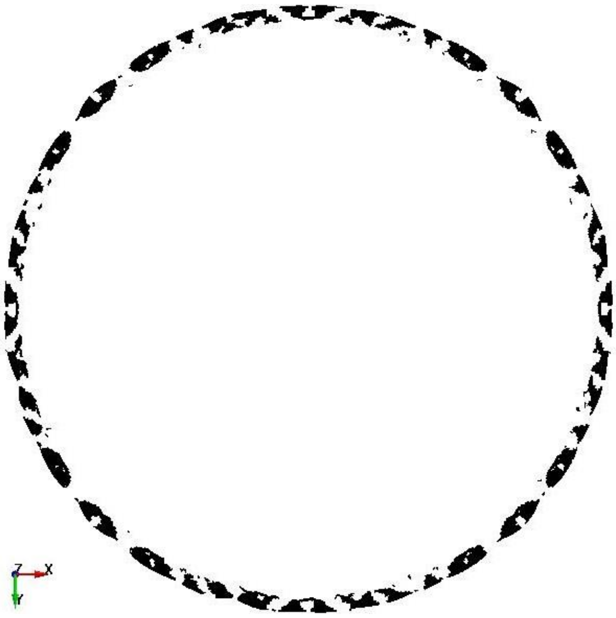
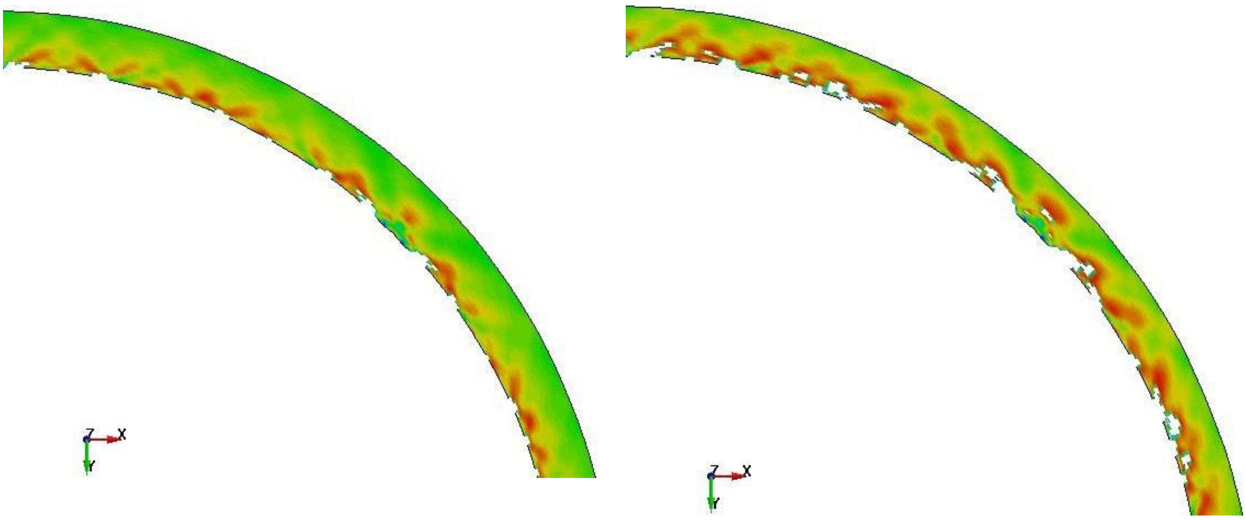


Figure 3. *Fragments LsDyna case 1*



t=1.3797e-5s *t=1.5597e-5s*

Figure 4. *Strain Fringe LsDyna case1*

Using this simple method to simulate ring fragmentation can be considered a little inappropriate since the percentage of eroded elements closes to almost 40% of the initial mass which can be problematic in comparing the obtained results with the experimental ones.

A more complex approach using LsDyna can be achieved by considering a natural dispersion of the material strength (erosion strain for the present paper) of the aluminum. This hypothesis of inherent heterogeneous character of every material was first elaborated by Weibull in 1939 based on his studies regarding quasi-static failure of materials.

Basically Weibull general formula involves the existence of three parameters. However, the most used form, this study included, involves only two parameters: shape and scale.

For the second LsDyna case using a MathCad routine a Weibull distribution of erosion strain value was generated. For the distribution a shape factor of 3 and a scale factor of 20 (-10% to +10% over the nominal value of failure strain) was adopted. By this method it was identified the number of elements having the same value for the failure strain (erosion strain) as depicted in ***Figure 5***. The next step was to generate a random list of elements and only then a value for the erosion strain for each element was assigned (***Figure 6***).

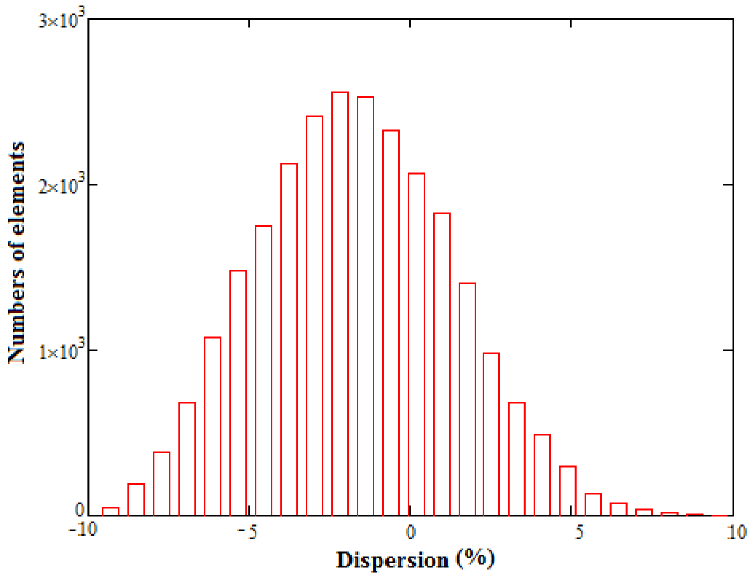


Figure 5. *Weibull Distribution*

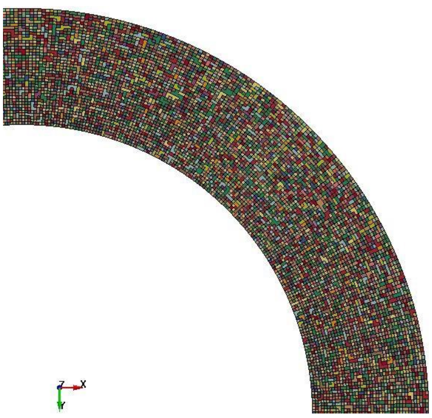


Figure 6. *¼ Ring geometry with Weibull distribution of erosion strain*

The results obtained for this case indicates 51 fragments and a residual mass of 86.526% of the initial mass. Details regarding final fragmentation and intermediate strain fringe are plotted in ***Figure 7*** and ***Figure 8***.

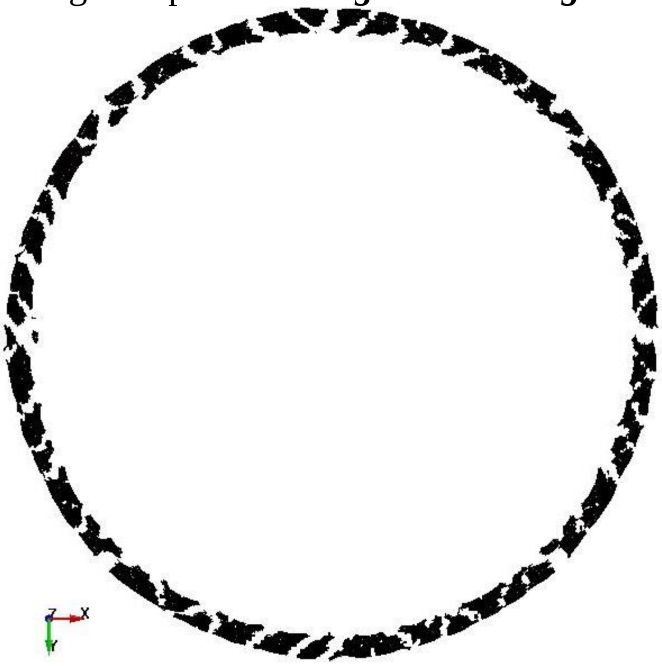
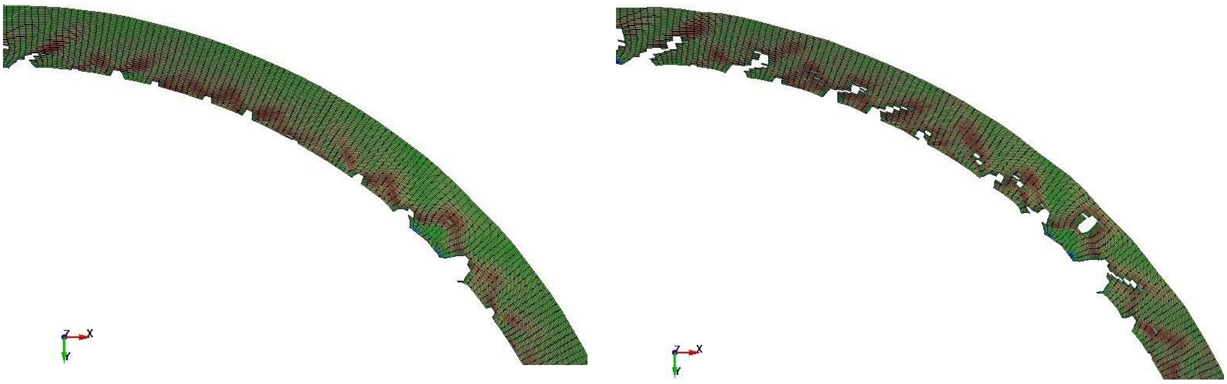


Figure 7. *Fragments LsDyna case 2*



t=1.3797e-5s *t=1.5597e-5s*

Figure 8. *Strain Fringe LsDyna case 2*

2.2 Autodyn Case

Like LsDyna software, Autodyn is a finite element software suitable for all kinds of engineering applications including military ones. As a matter of fact unlike LsDyna, Autodyn software is more devoted to military applications. For ring or shell fragmentation Autodyn offers two dedicated approaches related to failure model, that is stochastic failure and Grady spall.

Stochastic failure basically assumes a Mott distribution of the failure strain of the material while Grady spall accounts for the energetic based model developed by Grady.

Along with these two approaches, in order to ensure a comparative analysis with LsDyna results, two different cases were considered: constant failure strain and a Weibull distribution of failure (erosion) strain.

For Autodyn numerical simulations were used the same geometry and materials (TNT, AIR and AA1100-O). All considered cases involved an automatic fully coupled interaction between Euler parts (TNT and AIR) and Lagrange part (aluminum ring). The model used for this set of simulations is presented in ***Figure 9***.

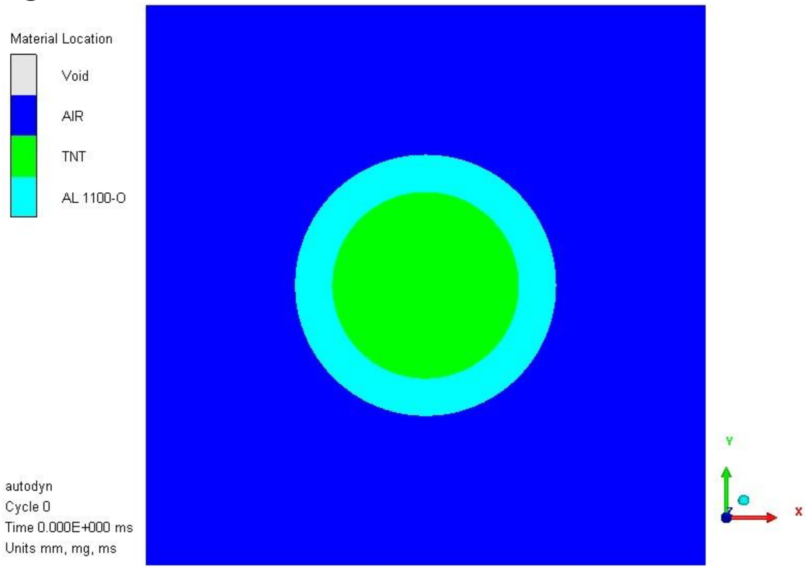


Figure 9. *Autodyn model*

The results in constant strain failure (***Figure 10***) and Grady (***Figure 11***) cases exhibit excessive failure which leads to extremely low residual mass.

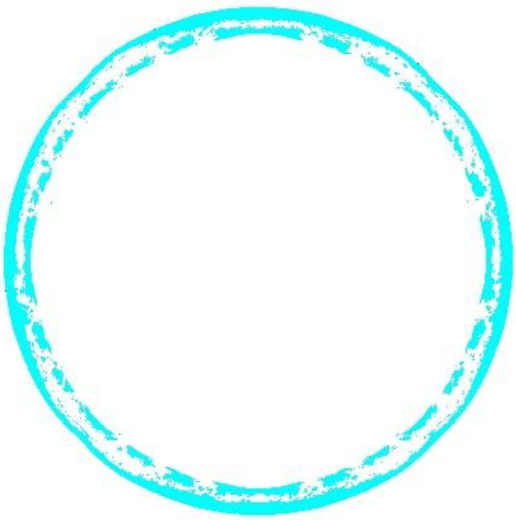


Figure 10. *Constant failure strain case*

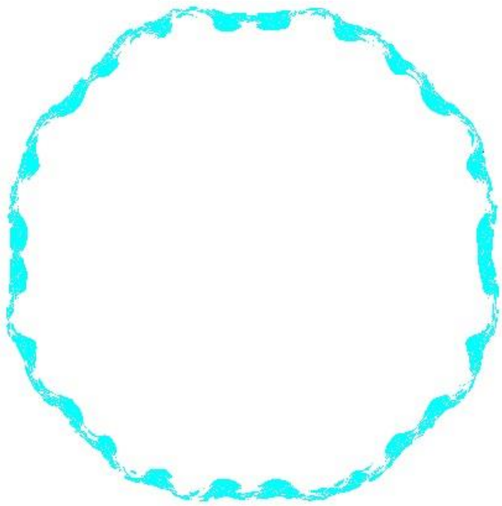


Figure 11. *Grady case*

As for the Stochastic case, the numerical simulation revealed a much more reasonable fragmentation (***Figure 12***) compare with Autodyn previous two cases. Using a stochastic variance of 16, a minimum fail fraction of 0.9 and a random seed distribution type the fragmentation finally leads to 27.988% residual mass and 450 fragments.

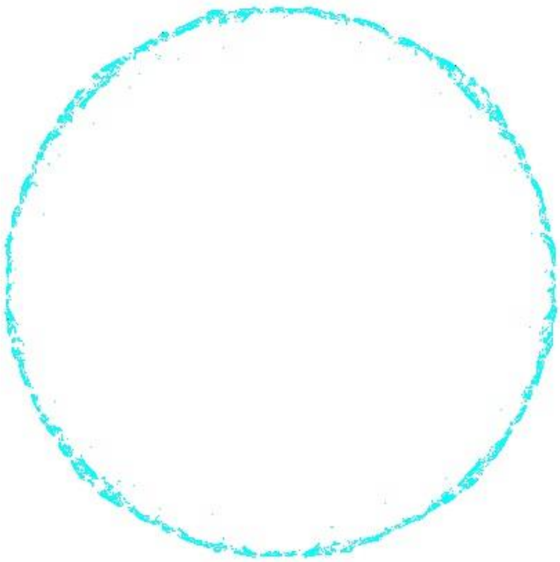
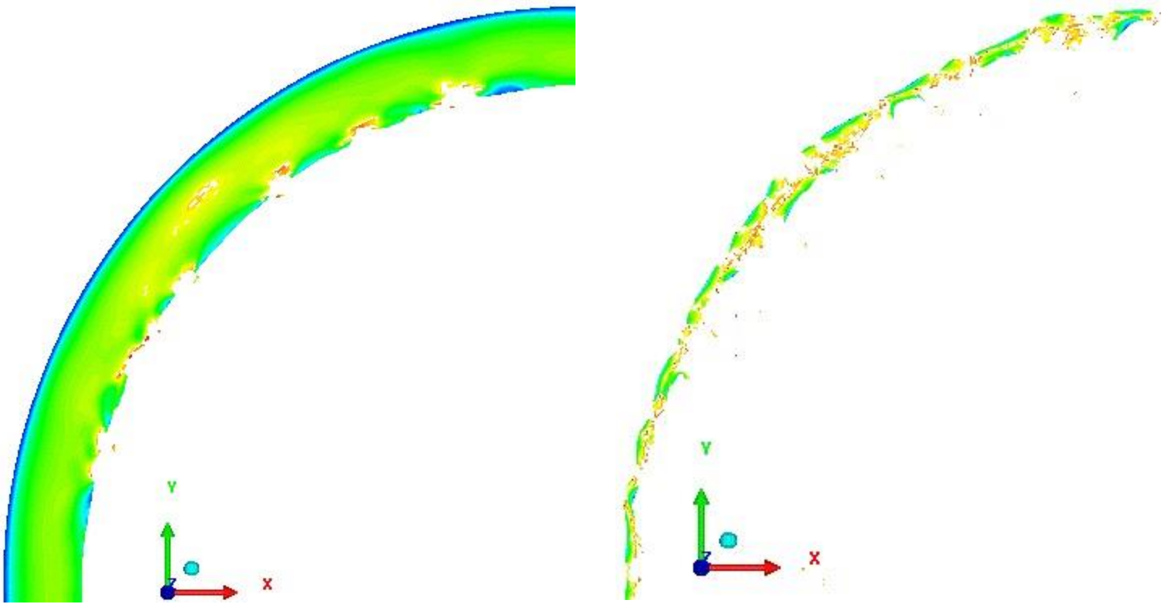


Figure 12. *Autodyn Stochastic case*

In terms of material strain fringe the results are depicted graphically in ***Figure 13***.



t=7e-6s *t=1.359e-5s*

Figure 13. *Strain fringe for Autodyn Stochastic case*

The last case considered for the Autodyn numerical simulation was based on implementation of a Weibull distribution of the material failure strain property previously used in Ls Dyna numerical simulation. The results for this case indicate 110 fragments with a residual mass of 79.103% of the initial mass (***Figure 14***). The details regarding strain fringe results are presented in ***Figure 15***.

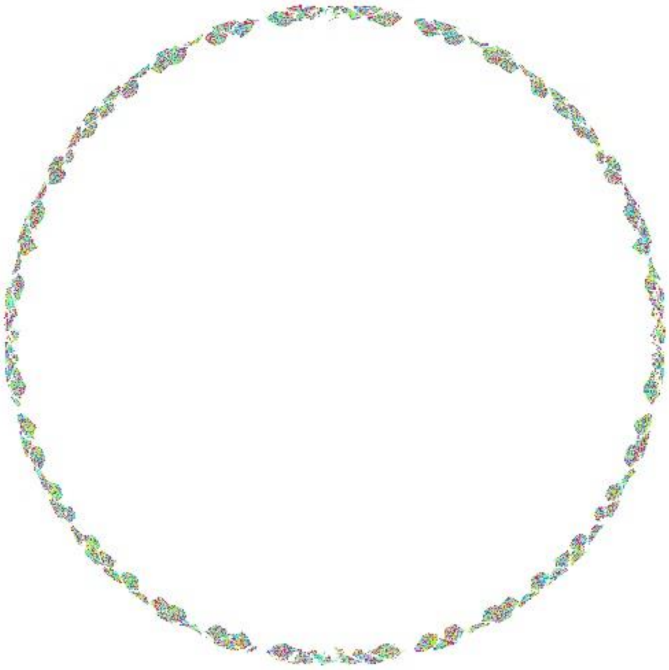
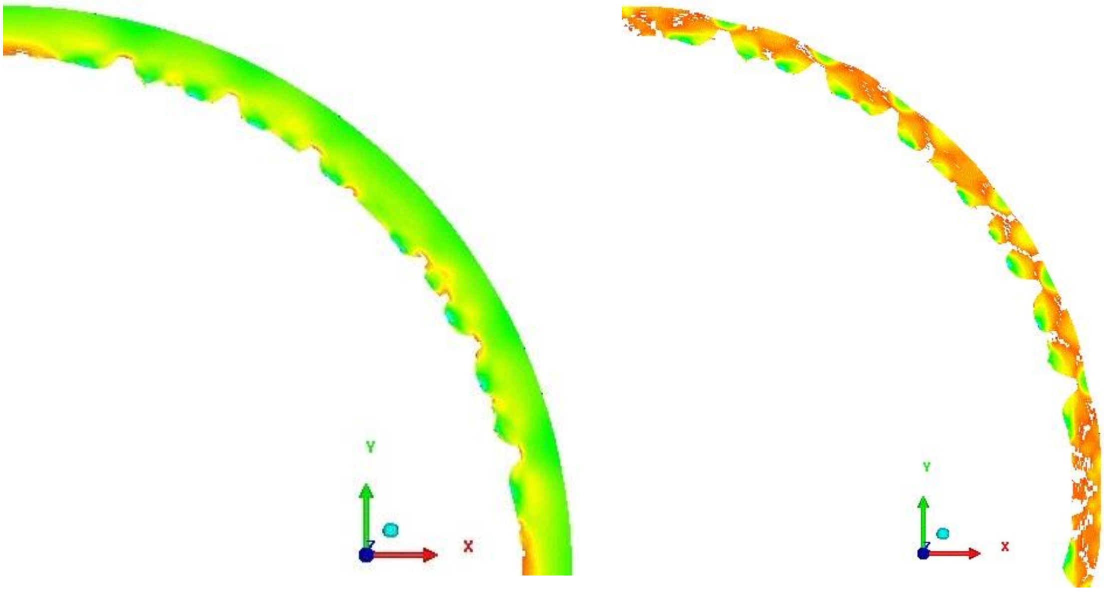


Figure 14. *Autodyn Weibull distribution case*



t=1e-5s *t=1.4e-5s*

Figure 15. *Strain fringe for Autodyn Weibull distribution case*

A comparative analysis of the above presented results for the two used commercial software pieces is hard to do since the recommended JWL EOS coefficients for TNT are not the same. However, in order to force such an analysis the previously-mentioned coefficients were altered in Autodyn to match the LsDyna ones. This modification was only made for the numerical simulation case which involved a material strength Weibull distribution. Slightly different findings were brought about by this approach. For this case only 93 fragments were identified summing 81.03% of the initial mass.

By looking at both LsDyna and Autodyn cases it can be concluded that LsDyna simulation resulted in a smaller number of fragments but in a higher residual mass value. Along with the presented results another aspect stood up namely fragments velocity. In LsDyna case the average resultant velocity for fragments was about 1140m/s while Autodyn simulation indicated a higher value of 1550m/s (***Figure 16 and Figure 17***). The 1550m/s value is closer to Gurney prediction of about 1745m/s.

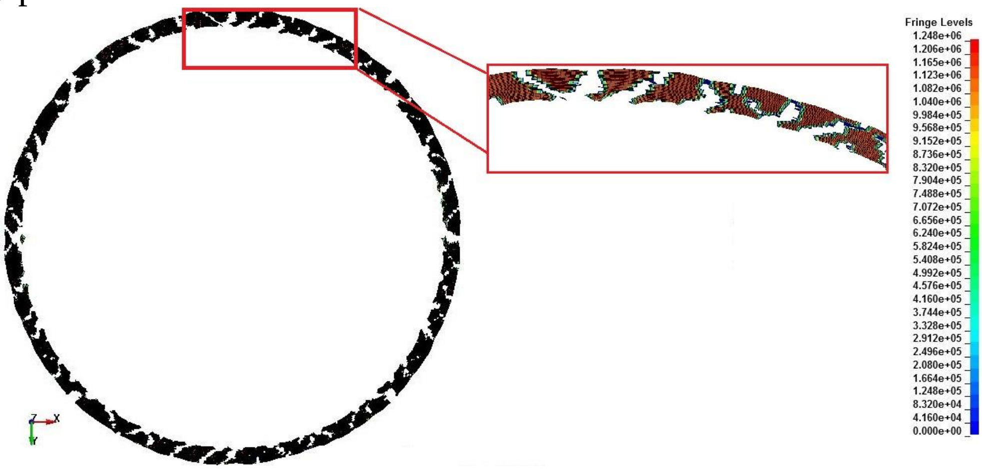


Figure 16. *Velocity fringe LsDyna case*

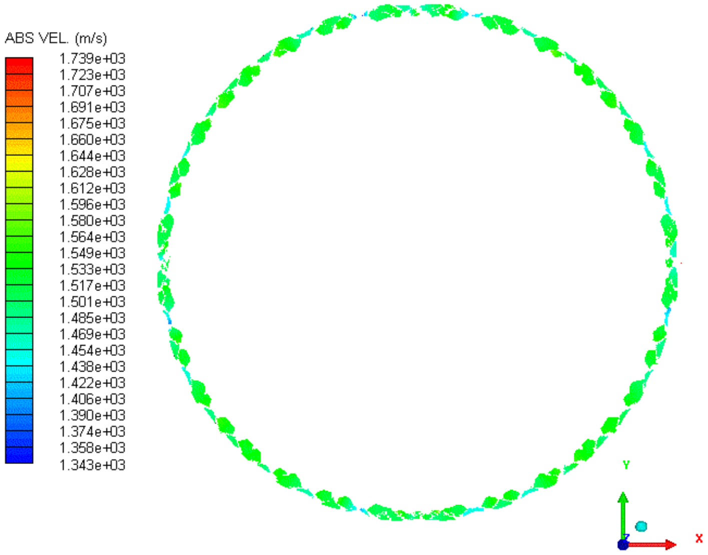


Figure 17. *Velocity fringe Autodyn case*

3. Conclusions

Shell or ring fragmentation is a complex issue with significant importance for both military and civil personnel since secondary type of blast injury and high pressure vessel failure incidents are tightly related to the fragmentation phenomenon.

Numerical simulation studies in certain condition can provide valuable inputs on intimacy of studied physical phenomenon.

The above presented findings should be considered with caution since no experimental studies had been conducted in order to evaluate fragment numbers and mass.

From the previous mentioned cases, the LsDyna case 2 simulation stands out as the case that resulted in the smallest fragment number and the largest residual mass depicting also a specific strain fringe (45° failure direction) consistent with other previous experimental published work.

Although the results of Autodyn Stochastic failure case differs from the Autodyn and LsDyna Weibull distribution cases, special attention must be paid to stochastic variance value since this parameter has an important influence on this particular fragmentation model.

The results elaborated in the present paper clearly suggest that both Autodyn and LsDyna commercial software are able to numerically model the ring fragmentation phenomenon.

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