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Impact analysis of side door of a car and bullet proof vest with material 'SAM2X5-630' using finite element analysis

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Abstract: The components which are bound to impact are subjected to deformation even though it may be for a small scale. The efforts are always on for finding the best material to take impact that has no failure or moreover, less plastic deformation. A newly found material which is glass matrix steel named as 'SAM2X5-630' has astounding high elastic limit of 12.5GPa. Thus it can take powerful impact & regain its original shape avoiding the deformation of component under impact. The paper is focused on performing the Finite element analysis to assess the behaviour of 'SAM2X5-630' steel under impact loading of side door of car as well as impact of bullet on bulletproof jacket on which the material is assigned. The displacement or deformation occurred during impact is found to be lesser than known materials like Kevlar in bulletproof vest and Aluminium alloy in car door.

1. Introduction
Applications like bulletproof vest, car door, mobile case, satellite which has tendency to get hit & deform has to prevent by using materials which can resist the impact load applied. For resisting the load applied, material has to be highly elastic to regain the original shape after impact and also tough enough to absorb the energy to not break into pieces. A newly found steel alloy amorphous matrix classified under 'bulk metallic glass' named as 'SAM2X5-630' has astonishing properties to fulfil the needs for impact resisting material. It is a highly disorganized crystalline structure but not enough to be categorized as brittle. The elastic limit of 'SAM2X5-630' is whooping 11.76 ± 1.26GPa which is way above the stainless steel elastic limit of 0.2GPa and even tungsten carbide which has value of 4.5GPa. Thus, this material can be considered for impact applications to realize its full potential. Hence, this paper focuses on performing the Finite Element analysis on two cases mainly the impact of bullet on vest & impact of block on car door where vest and car door is considered to be made of 'SAM2X5-630'.

2. Literature Review:
Khanolkar et.al [1] conducted experiment on bulk metallic glasses in the past for exploring the mechanical properties to promote the use of such materials in the field. Much efforts are took to find better composition of metallic glass which has best of both sides of glass's disorganized structure as well as metals' elastic nature. Previously, experiments were mostly conducted on Zr-based alloys which exhibited elastic limit of 7GPa.
The newly found 'SAM2X5-630' which is highly elastic Fe-based alloy is quite less explored yet. This alloy bounces back when deformed due to sudden impact due to its high limit of elasticity. Material may get largely deform under sudden impact but completely regains its original shape because of its mechanical properties. Puran Singh et.al [2] conducted experiments to study the material microstructure

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of this steel alloy by using X-rays diffraction. For the first time, studies were conducted on the amorphous steels response to shock wave compression by students of Caltech University.

3. Methodology: This project focuses on the behaviors of material with its counterpart used in their respective applications. The deformation, stresses are calculated & compared to understand the behavior of metal alloy. Methodology is described for two applications.

1. Car door impact
2. Bullet impact on vest

3.1. Car door impact

a) Modelling

Car door model was created using Solidworks software and imported into Ansys workbench 2016.

b) Material Assignment is given in Table 1

Table 1. Material assignment cases for car door

Case 1	Car door material: Al alloy Block material: Structural steel
Case 2	Car door material: SAM2X5-630 Block material: Structural steel

c) Meshing details of car door & block

Car door & block is discritized into finite elements with number of elements 22189 & no of nodes 22675.

d) Boundary conditions applied are as follows:

Block velocity: 35.76 m/s

Car door: stationary.

3.2. Bullet impact on Vest

a) Modelling

Bulletproof Vest model is created using Solidworks software and imported into Ansys workbench 2016.

b) Material Assignment is given in Table 2

Table 2. Material assignment cases for vest

Case 1	Vest door material: Kevlar layer Bullet material: Antimony
Case 2	Vest door material: SAM2X5-630 Bullet material: Antimony

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c) Meshing details of bullet & vest

Vest and bullet is discritized into finite elements with number of elements 2082 & no of nodes 3186.

d) Boundary conditions applied are as follows:

Dimension of fiber materials:
Thickness of jacket material = 1.5mm
Dimension of bullet proof material = 500mm x 500mm
Kevlar149 is taken for the analysis Dimension specification of bullet:
Diameter of bullet = 10mm
Velocity of bullet = 900m/sec

4. Manufacturing process of SAM2X5-630: Metallic glass composite is manufactured using powder metallurgy method. Fig 1 shows the synthesis process step by step as shown below.

The composition of SAM2X5-630 is

$$Fe_{49.7}Cr_{17.7}Mn_{1.9}Mo_{7.4}W_{1.6}B_{15.2}C_{3.8}Si_{2.4}$$

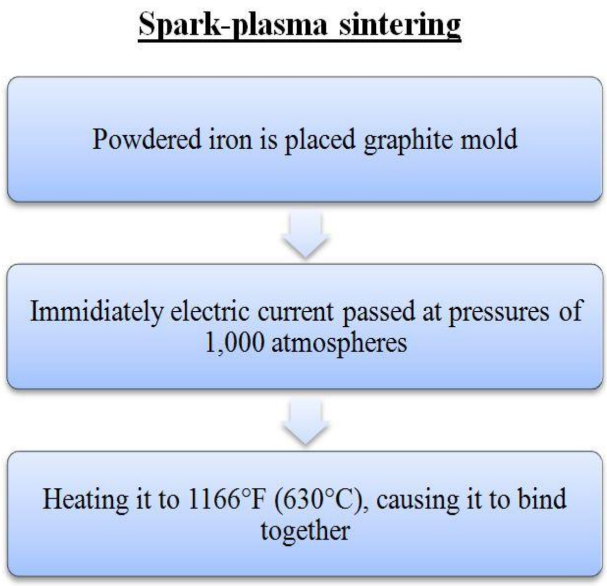

Figure 1. Synthesis process

5. Material properties of materials:

SAM2X5-630 material properties is shown in table.3.

Table 3. SAM2X5-630

Properties	Value

Density (g/cm3)	7.75
Young's Modulus (Mpa)	248000
Poisson's ratio	0.23
Melting Temperature (K)	1133

Aluminium properties is shown in table 4 and Antimony properties is shown in table 5.

Table 4. Aluminium properties

Properties	Value
Density (g/cm3)	2.77
Young's Modulus (Mpa)	77000
Poisson's ratio	0.33
Melting Temperature (K)	933.5

Table 5. Antimony properties

Properties	**Value**
Density (g/cm3)	6.7
Young's Modulus (Mpa)	77759
Poisson's ratio	0.28
Melting Temperature (K)	903.75

Kevlar149 properties is shown in table 6

Table 6. Kevlar149 properties

Properties	**Value**
Density (g/cm3)	0.733
Stiffness	**Stiffness Matrix**
C11, (Mpa)	3252.2
C22, (Mpa)	13058
C33, (Mpa)	13068
C12, (kpa)	0.075610
C23, (kpa)	0.063199
C31, (kpa)	0.312318
Poisson's ratio in X direction	0.23

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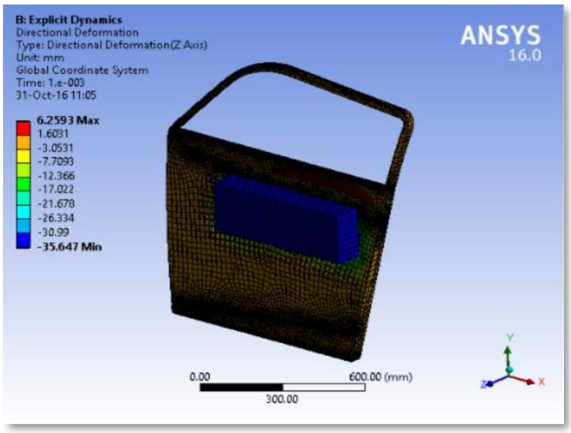
Poisson's ratio in Y direction	0.36
Poisson's ratio in Z direction0	0.23
Johnson Cook Failure Values	
Damage Constant 1	0.16804
Damage Constant 2	0.034994
Damage Constant 3	-2.44
Damage Constant 4	-0.045
Damage Constant 5	0.919
Melting Temperature (K)	1800

6. Results: Results are observed for two cases

1. Car door impact
2. Bullet impact on vest

61. Car door impact:

Directional deformation for Al alloy and SAM2X5-630 is shown in Figure 2 and Figure 4 respectively. Deformation graph of material Vs. Time is shown in Figure 3 , Figure 5, Figure 6 and Figure 7 for Al alloy and SAM2X5-630 respectively. As seen below, maximum deformation in Al door is 6.25 mm whereas in SAM2X5-630 is 0.51 mm.



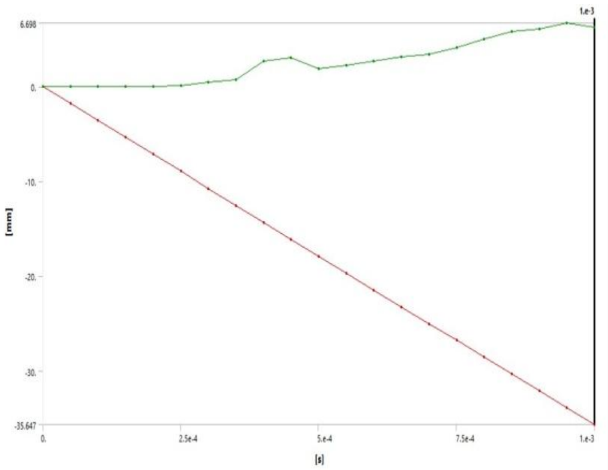
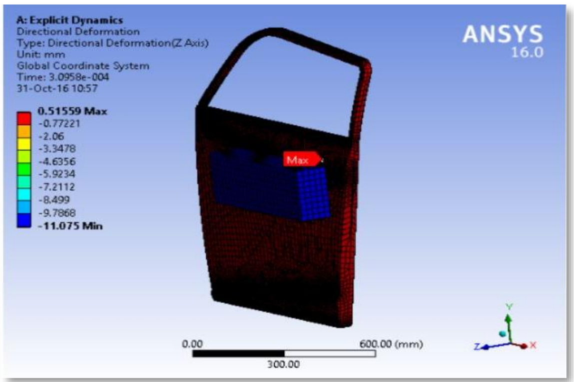


Figure 2. Directional Deformation in Al alloy **Figure 3**. AL directional deformation in impact direction vs. time graph



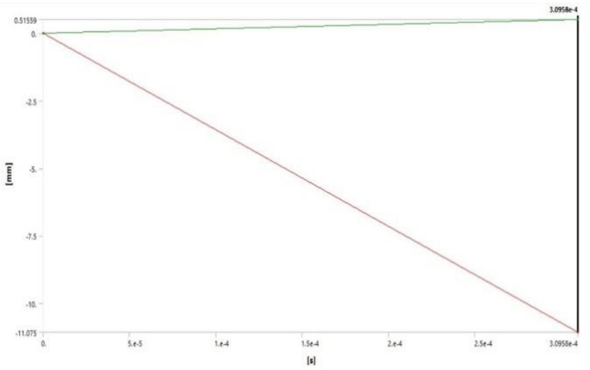
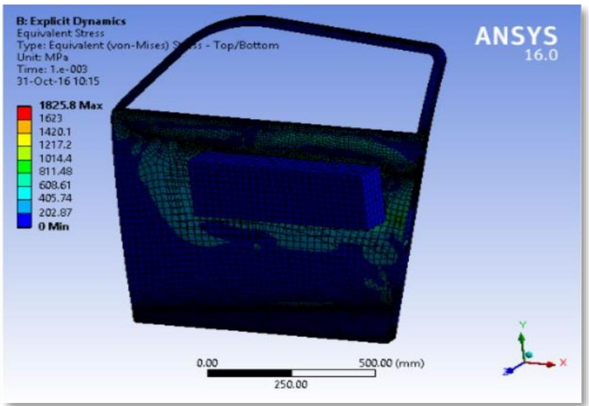


Figure 4. Directional Deformation in SAM2X5-630

Figure 5. SAM2X5-630 directional deformation inimpact direction Vs time graph



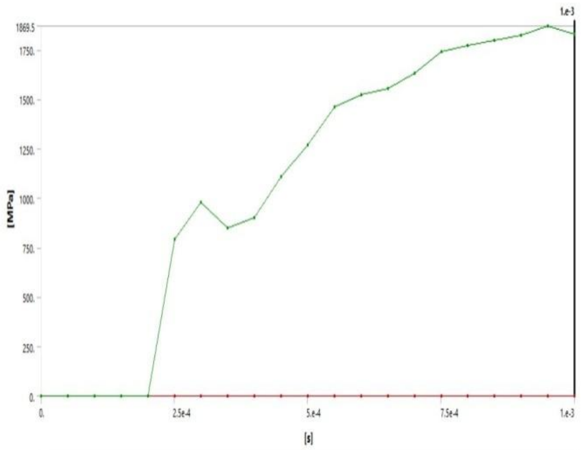
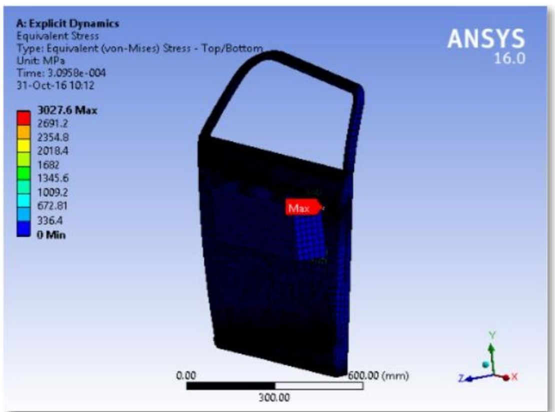


Figure 6. Stress Vs Time Graph for impact on Al **Figure 7.** Stress generated in Al alloy door



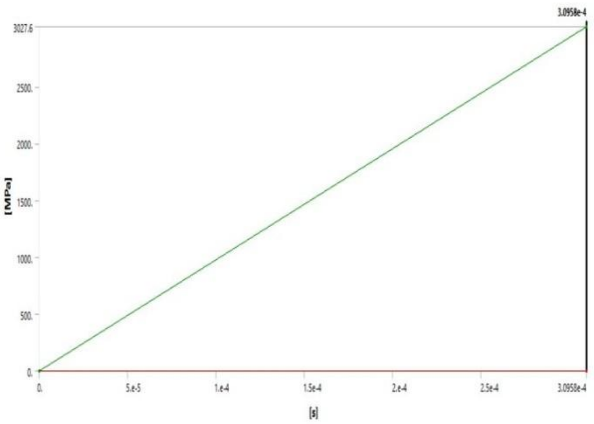


Figure 8. Stress generated in Al alloy Stress in SAM2X5-630

Figure 9. Stress generated in SAM2X5-630 graph

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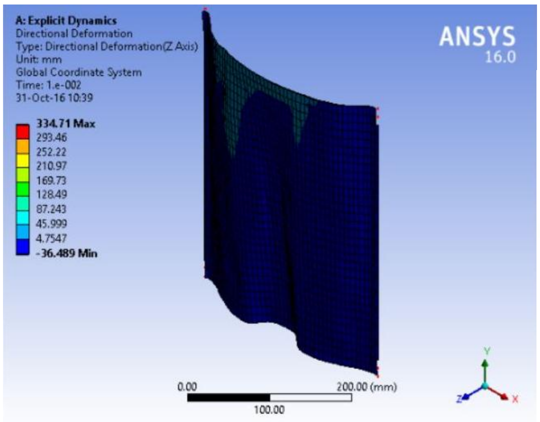
As seen above, maximum stress generated in Al door is 1825.8MPa as shown in Figure 6 whereas in SAM2X5-630 is 3027.6MPa as shown in Figure 8 and Figure 9 which is well within the elastic limit. Thus, it is able to regain original shape.

6.2. Bullet impact on vest: Directional Deformation results for bulletproof vest as shown in Figure 10 and Figure 11 for material Kevlar and SAM2X5-630 and their respective graphs of Deformation vs. time explained in Figure 12 and Figure 13.



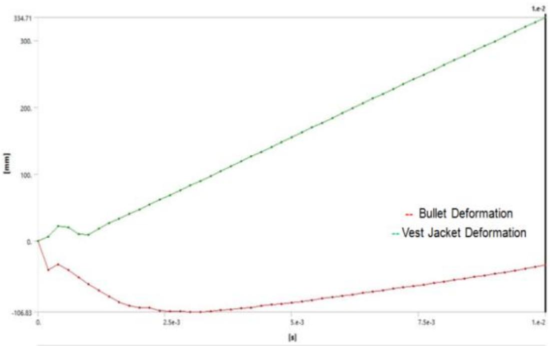
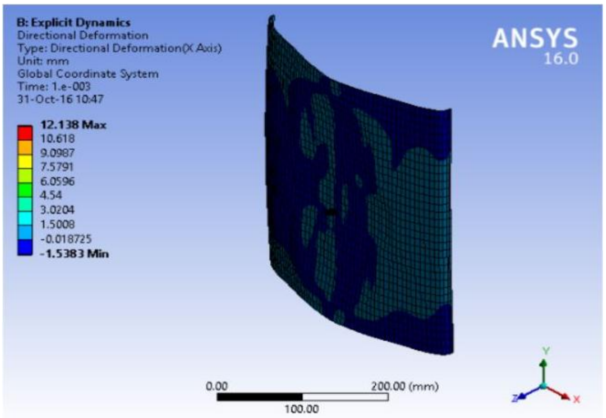


Figure 10. Directional Deformation in Kevlar

Figure 12. Kevlar layer directional deformation in impact direction vs. time graph



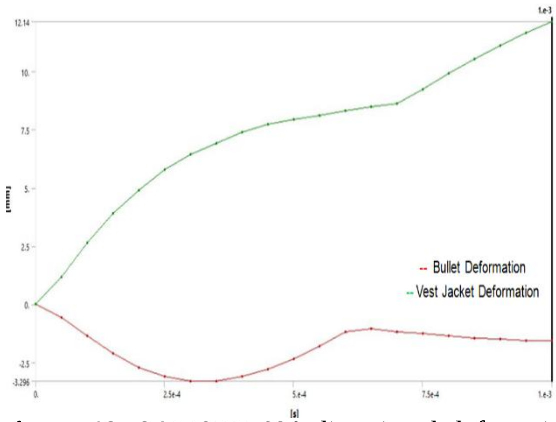


Figure 11. Directional deformation in SAM2X5-630

Figure 13. SAM2X5-630 directional deform in impact direction Vs time graph.

As seen above, maximum stress generated in Kevlar layer is 231MPa as shown in Fig 12 whereas in SAM2X5-630 is 586MPa as shown in Fig 13 which is well within the elastic limit. Thus it is able to regain original shape.

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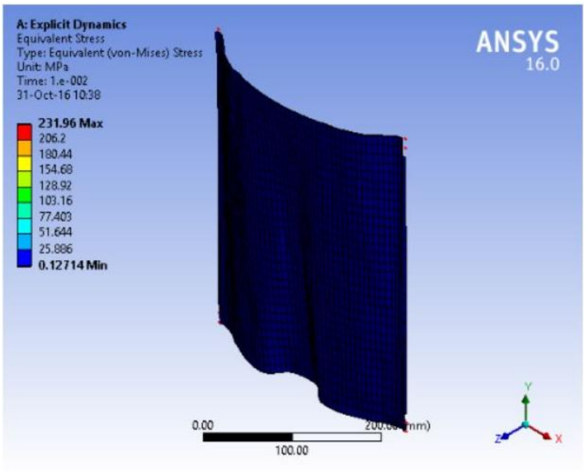


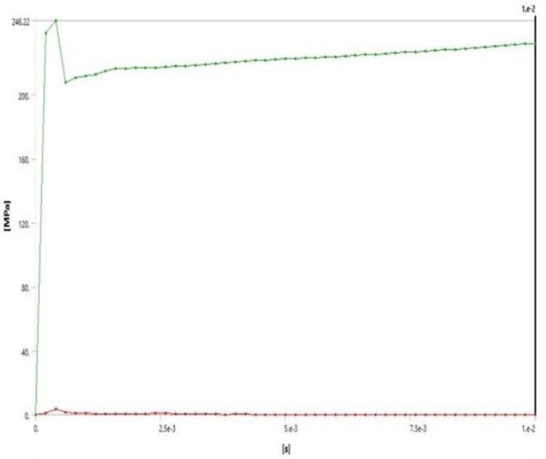
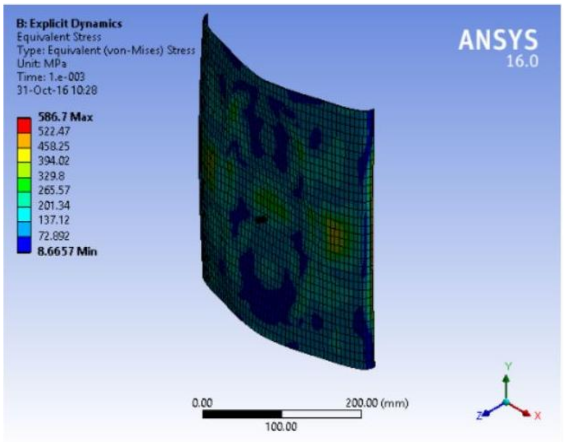


Figure 14. Stress generated in Kevlar layer

Figure 16. Stress Vs time graph in Kevlar layer

As seen above, maximum stress generated in Kevlar layer is 234MPa as shown in Figure 14 and Figure 15 whereas in SAM2X5-630 is 586MPa as shown in Figure 16 and Figure 17 which is well within the elastic limit. Thus it is able to regain original shape.



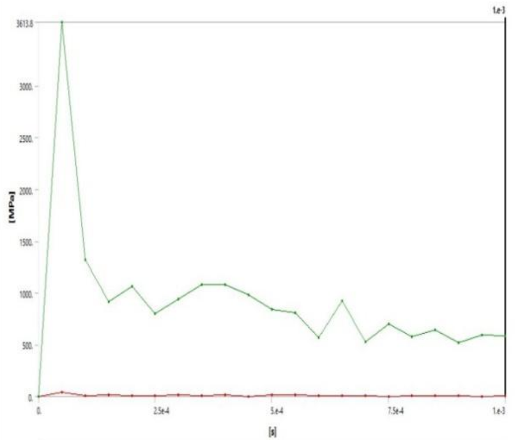


Figure 15. Stress generated in SAM2X5-630

Figure 17. Stress Vs time graph inSAM2X5-630

7. Results and Discussion: In bullet proof jacket, standard 14-15 layers of Kevlar is used & its total thickness is 25mm. Thus, one layer of Kevlar is around 1.5 mm. Analysis on one layer shows directional deformation of 334.7 mm whereas for SAM2X5-630 material layer of 1.5mm shows directional deformation of 12.138 mm. For 15 layers of Kevlar, the directional deformation reduces to 14.8 mm. Thus a 1.5 mm metallic glass layer shows better impact resisting behaviour than 15 layers of Kevlar. The stress generated in metallic glass is well within the elastic limit which makes it able to regain its original shape. The actual weight of 15 layers of Kevlar used in bulletproof jacket is approximately 2.14 kg and derived weight of one layer metallic glass from model is approximately 1.5 kg. Therefore,SAM2X5-630 lies ahead of currently used materials in their respective applications in impact loading conditions.

8. Conclusion: In the ongoing race to find new material to perform better under impact loading, SAM2X5-630 proves to be a new benchmark. As per testing and understanding the behaviour of metallic glass composite with respect to material which is considered to be fit at respective applications like Al alloy for car door or Kevlar fabric for bulletproof vest, SAM2X5-630 stands ahead of them. Application of such a highly elastic material can be found in other studies like impact of meteorite on satellite shields or even impact of mobile body falling on floor. Thus impact borne application can be highly benefited by inheriting the properties of SAM2X5-630.

References

[1] Khanolkar, G.R., Rauls, M.B., Kelly, J.P., Graeve, O.A., Hodge, A.M. and Eliasson, V., 2016. Shock Wave Response of Iron-based In Situ Metallic Glass Matrix Composites. *Sci. reports*, **6** 22568

[2] Puran Singh, Vikas Malik, Priyawart Lather, *Analysis of composite materials used in bullet proof vests using fem technique,* International Journal of Scientific & Engineering Research, 4, **5** 2013.

[3] Nitin S.Gokhale,*Practical Finite to Infinite*, (2008).

[4] Adam wiśniewski, Michałgmitrzuk, Selection of the number of the kevlararmour layers in the numerical analysis of the 5.56 mm projectile penetration with the use of the ansys - autodyn v12.1.0 program