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The impact digit modeling and steel projectile penetration having tumbling with aluminum targets

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ABSTRACT
The main aim of the study was to investigate the results of impact digit simulation and projectile penetration with tumbling in aluminum-metallic targets that the limited element LS-DYNA software is also used in order to analyze the related digit analysis in this regard. In this analysis the deformable projectile and material behavior model of aluminum target was considered as rigid-plastic along with a non-linear work-hardening in the related study. According to figure 1, the penetration process includes three phases of target erosion, plugging and hole enlargement and the plugging phase is categorized into four cratering, plug formation, plug separation and plug slipping; the obtained results from the digit simulation with experimental data and recent analysis theories results were compared and the studies showed that the simulation results had suitable coincidence with the experimental data in this regard.
Key words: *projectile, tumbling, digit analysis, impact*

INTRODUCTION
One of the most essential analytical methods of Ballistic impacts is subjected to the digit simulation using the limited element models. One of the most famous and well-known software in the penetration digit analysis and nonlinear impact and nonlinear limited element code is LS-DYNA devoting to the analysis of dynamical issues under the large deformations impact, hyper and low velocity impacts, Ballistic penetration and wave distribution. According to figure 2, a projectile with impact angle $\theta 0$ than projectile axe is achieved along with rational speed of projectile $\omega 0$ and velocity v0 to the surface of the target. The main angle between the projectile with the speed of central mass coordination $\gamma 0$ and the angle between the speed coordination vertical on the target surface of angle $\beta 0$ is called Oblique angle. It is specified that the equation will be as following: $\theta 0 = \gamma 0 - \beta 0$
Like other limited elements codes, LS-DYNA is seeking a response for the momentum equation satisfying the displacement and territorial circumstances on the external and internal cases in this pavement. The energy equation is also integrated towards the time to calculate the mood equation and general energy balance in this regard. The integral method is based on the central differential or fluxion method and the degree of speeds and displacements are evaluated as momentary in this case.
Lee and Gold Smith (Li & Goldsmith, 1996) gave a model for the external impact from the projectiles axe in metallic targets with moderately thick. In this method, the penetration process in four phases including erosion, plugging, hole enlargement and petaling categorized that the rigid projectile and material behavior model is considered as rigid-plastic and the equations were also extracted in every phase that the results of the modeling had suitable coincidence with the experimental data in the present study.

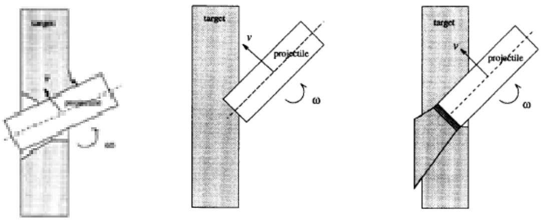

Figure 1: process of projectile penetration with tumbling movement in target along with moderately thick

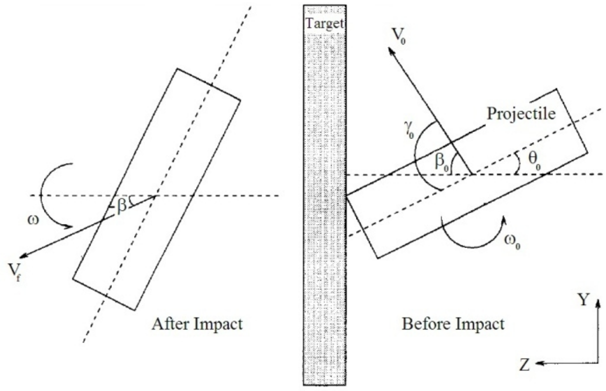

Figure 2: status of projectile impact to target and early parameters before the impact

Another analytical model was carried out by S. Feli et al (Tate, 1967) for the penetration of projectiles with tumbling in thick metallic targets. In this model, the penetration process is categorized in four phases of erosion, plugging, hole enlargement and petaling. In the related analysis the deformable projectile and target material behavior model were considered as rigid-plastic with nonlinear work hardening that the results were also obtained by the use of MATLAB Software in this regard. The obtained results had also suitable coincidence with the experimental data. The condition of erosion construction in projectile using Tate Equation (Alekseevskii, 1966) and Alekseevski (Hallquist, 2001) by the condition of dynamical delivery tension in relation to the enlarge projectile than the target (σD yp > σD yt) is that the first impact speed is devoted truly in the below equation:

(1) $$V_0 \geq \sqrt{\frac{2(\sigma_{yp}^{D} - \sigma_{yt}^{D})}{\rho_t}}$$

In this article the digit impact and projectiles penetration with tumbling in alumina targets is established based on S.Feli et al analytical model (Tate, 1967) and the obtained results were compared with the recent theories and experimental data that suitable coincidence was observed from the results comparison in this pavement. In this study the dimensional specifications and mechanical features of target and projectile were given in table 1.

Table 1: mechanical specifications and features of target and projectile (2)

Mechanical specifications with dimension	Steel projectile	Aluminum 6061-T6 Target
(kh/m3) p	7977	2780
E (Gpa)	210	70
Dynamical delivery stress σDy (Mpa)	1393	295
V: powassion coefficient	0.3	0.29
R: projectile radius	6.35	--
Thickness H (mm)	--	12.7
Length of projectile L (mm)	38.1	--
M: friction coefficient	0.05	

Modeling method:

The equation of Johnson-Cook was applied in order to simulate the behavior of erosion projectile and metallic target. The material model of Johnson-Cook is applicable for describing the behavior of cases with high strain and temperature such as metals; one of its applicable indices is subjected to the impact and Ballistic penetration. The related model is defined for measuring the stream stress as following (Zukas, 1990):

(2) $$\sigma = [A + B\varepsilon^{n}][1 + C\ln\dot{\varepsilon}^{*}][1 - T^{*m}]$$

That A, B, C, m, n are the fixed degrees of temperature and air

(3) $T^* = \frac{T - T_{room}}{T_{melt} - T_{room}}$

T: working temperature
T room: environmental temperature
T Melt: Melting point

In this behavioral model, by determining the breakage strain coefficients, it can be controlled by the breakage of the elements and their elimination. The material model of Johnson-Cook for measuring the breakage strain is as following (Zukas, 1990):

(3) $\varepsilon_f = [D_1 + D_2 \exp(D_3 \sigma^*)][1 + D_4 \ln \dot{\varepsilon}^*][1 + D_5 T^*]$

Where σ* is the proportion of hydrostatic stress (moderate) to the effective stream stress. The coefficients of D1, D2, D3, D4 and D5 are the breakage stress coefficients for every special type; these coefficients are measured as experimental coefficients along with completion of experimentation; the whole mentioned fixations have been given in table 2. When the measured stress in every element is reached to the breakage stress, the same element will be eliminated from the software analysis.

Table 2: the fixations of Johnson-Cook material behavior for the projectile and target (Feli, 2008**)**

Related fixation	Steel projectile	Aluminum 6061-T6 Target
(kh/m3) p	7830	2700
Cp (specific heat) (J/kg0k)	477	875
T melt (0k)	1793	877
A (Mpa)	792	335
B (Mpa)	510	85
C	0.014	0.012
N	0.26	0.11
M	1.03	1
D1	-0.8	0.14
D2	2.1	0.14
D3	-0.5	-1.5
D4	0.002	0.018
D5	0.61	0

The mood equation used for describing the projectile materials and target is Grunisen mood equation. This equation is defined as following:

(4) $$P = \frac{\rho_o C^2 \mu [1 + (1 - \frac{\gamma_o}{2})\mu - \frac{a}{2}\mu^2]}{[1 - (S_1 - 1)\mu - S_2 \frac{\mu^2}{\mu + 1} - S_3 \frac{\mu^3}{(1 + \mu)^2}]} + (\gamma_o + a\mu)E$$

Where,

P: hydrostatic pressure or stress
E: energy in volume
C: sound speed or elastic wave in metal
S1, S2, S3, a: fixed coefficients for every material
Γ0: Grunisen Gamma
M is based on V equals to (2):

(6) $\mu = \frac{1}{V} - 1$

Table 3: fixations of Grunisen mood equation for projectile material and target

Related fixation	Steel projectile	Aluminum 6061-T6 Target
S1	1.49	1.38
S2	0	0
S3	0	0
C (m/s)	4570	5290
γ	2.17	2.14

The whole impact surfaces should be defined during the process of probable impact such as the projectile impact with target in software environment. After the establishment of territorial conditions in the whole elements, it should be specified the relationships between the defined materials, their features and mood equations regarding together. In other words, it should be determined that the system components such as projectile and target and how or what specifications have got mood equations in this regard. The last phase in simulation process is to determine the assumed time of the impact moment to the end of the penetration process that they assumed about 100 micro-seconds in the study.

RESULTS AND DISCUSSION

After the completion of modeling phase in FEMB setting and its delivery to LS-DYNA and problem-solving, the results of the simulation can be observed as various forms such as contours, figures and diagrams.
Figure 3 shows the process of metallic projectile penetration into the aluminum target. In the wee of projectile impact, the target separation starts happening in this case. These separations happen during micro-seconds impact through the pressure stress in that area. Due to the initial speed of projectile (565 m/s) happening higher than the Ballistic system limit, the total target thickness is destroyed using the equation (Li & Goldsmith, 1996) for calculating the projectile specifications and the target speed is lower than the limit speed in relation to the erosion process; during this process the rigid and erosion projectile is not felt; the penetration process lasts about 103'' micro-seconds in this case.

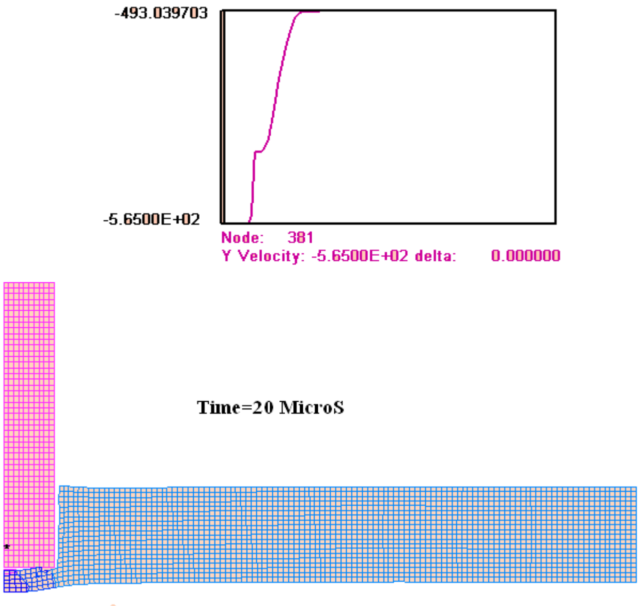

Figure 3: penetration process of metallic projectile into the aluminum target

In figure 4, we observe that the highest stress in impact area is seen when the projectile is clashed to the target happening in front of the projectile. After the penetration of the projectile into the target, a pressure wave is moved along with the projectile movement towards the rear direction of the target and after the reflection, it will back as a strengthening wave.

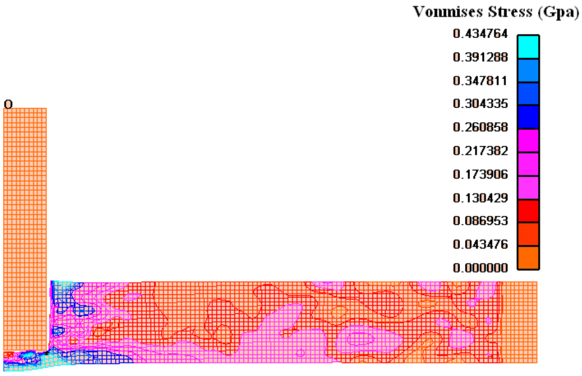

Figure 4: maximum pressure stress in impact area of projectile to aluminum target

Table 4: comparison of digit analytical results and two results of recent experimentations in vertical impact

Results of exit speed (m/s)						
Projectile			Plug			V 0 (m/s)
LS-DYNA results	Reference model (2)	Experimental (1)	Results of LS-DYNA	Reference model (2)	Experimental (1)	
493	501	478	498	501	514	565
332	332	323	334	332	349	402

In table 4 a comparison has been carried out between the recent experimental results for the vertical impact (Li & Goldsmith, 1996), reference analytical models (Tate, 1967) and simulation by the help of LS-DYNA Software. Due to the related table, the prediction of reference analytical model (Tate, 1967) and digit simulation for the ultimate speed of plug when getting exit of the target being close to the related phase of plug slipping and experimental data in this regard. However, the software prediction is closer to experimental data for the projectile end speed during its exit from the target and end of hole enlargement phase. In figure 5 the change of projectile length is shown based on penetration time; it is observed that there is no suitable convergence between the simulated results and model calculation (Tate, 1967). The coordination from the analytical model calculations shows a frequent length reduction of projectile during the first and second phases of the penetration process. In the third phase due to the rigidity of the projectile, its length never gets reduced being fixed to the end of the penetration process while the coordination obtained from the digit simulation has got sharp slope in this case. The software of LS-DYNA will remove the element from the system when the strain of an element is reached to the breakage strain. For the reason, it is predicted higher length failure for the projectile in the related diagram.

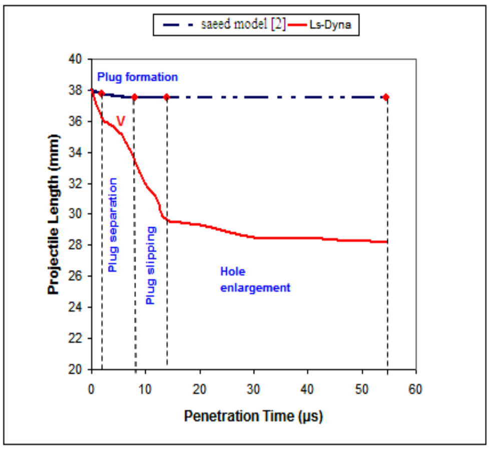

Figure 5: length deformation of projectile (L) based on penetration time and reference analytical calculations (2) and limit element software LS-DYNA

CONCLUSION

The given digit model in this article analyzed the effects of projectile axial tumbling in impact and penetration into the aluminum-metallic targets with moderately thickness. The degrees of plug exit speed of the target and the left speed of projectile after the exit have been predicted from the target by the digit model being coincident with the experimental results.

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