OA-2 327

MILITARY TECHNICAL COLLEGE

CAIRO - EGYPT

1- EFFECT OF PROJECTILE IMPACT VELOCITY AND TARGET THICKNESS
2- ON PENETRATION RESISTANCE OF MILD STEEL

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4- ABSTRACT

In the present paper, results of ballistic tests with 7.62 mm rifle lead bullets impacting and perforating as-received mild steel thin plates at normal incidence are reported. In order to separately investigate the effects of projectile impact velocity and target plate thickness on penetration resistance of the plates, seven impact velocities ranging from 373 to 608 m/s and four plate thicknesses up to 4 mm were considered. A special setup was used in the tests, which allows for the measurement of impact and residual velocities. Moreover, time histories of projectile displacement and velocity as well as resisting force of target plate during the course of penetration were predicted employing the five-stage analytical penetration model of Ravid and Bodner [1]. These histories were analysed and compared with predictions of other penetration models qualitatively. Moreover, experimentally obtained results were compared quantitatively with predicted values and the agreement was found to be reasonable. It is felt, however, that better agreement could have been achieved, if dynamic mechanical properties and consequently a more appropriate constitutive equation had been available.

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INTRODUCTION

To properly describe the penetration process, many parameters are found to be involved, which can be grouped into : impact conditions, projectile characteristics and target characteristics, as shown in Fig. 1. The role of individual parameters and resulting failure modes of target are discussed at length in Refs. [2-4].

This work is aimed at investigating the effect of impact velocity and target plate thickness on the penetration capability of the standard 7.62 mm rifle bullet in normal impact. Furthermore, the Ravid-Bodner analytical penetration model [1] is employed to predict time histories of projectile displacement and velocity as well as target resistance during the course of penetration. Other relevant parameters are also calculated and compared with experimental results.

EXPERIMENTAL PROCEDURE

Target plates were cut from mild steel sheets of 1, 2, 3 and 4 mm thickness. Because of the effect of mechanical properties of plates on its penetration resistance, mechanical tests were performed on standard flat specimens cut in two perpendicular directions in the plane of the sheets. Microhardness measurements were taken through the thickness for each specimen and average values were obtained. Load-displacement curves were autographically recorded, thus allowing the engineering stress-strain curves to be deduced. Values of strength, ductility and toughness were consequently calculated.

For each firing test performed, impact and post-perforation velocities were measured using the setup shown schematically in Fig. 2. In each and every measurement, the average of at least two firing test results obtained under similar test conditions, whose values differed by no more than 3%, was taken as the basis for analysis. In order to change impact velocity, rounds were especially filled with propellant charges ranging in mass from 1.0 to 1.6 g and differing by 0.1 g each. Further details of ballistic testing can be found elsewhere [3,4].

RAVID-BODNER MODEL

This two-dimensional model is confined to plugging failure and rigid, flat ended projectiles. It divides the penetration process into five distinct but interconnected stages, as shown in Fig. 3. The material strain-rate dependence is considered in the model. A plastic flow (velocity) field surrounding the projectile at each increment of penetration is assumed in each stage.

Because of space limitation, the general mathematical formulation of the model, which is rather lengthy and involved, will not be included here. Rather, the reader is referred to the original work, Ref. [1], and to Ref. [4], where a complete and detailed development of the model is presented. In the latter reference, it is explained how the governing equations constituting the model were cast into a FORTRAN computer program. This program can predict the time histories of projectile velocity and displacement into the target as well as the resisting force exhibited by the target on the projectile. It can also provide plug mass and dimensions, perforated hole geometry as well as velocities of separated plug and projectile. The only input data for the program are projectile length, diameter, density and impact velocity as well as target thickness, density and mechanical properties.

RESULTS AND DISCUSSIONS

Average values of Vicker's microhardness measurements on the plates was found to be 1442 MPa for a load of 0.5 N (50 g_f). A representative load-displacement trace obtained during tensile testing of the 3-mm plates is shown in Fig. 4, together with the corresponding engineering stress-strain curve. Values of yield and ultimate strengths as well as strain to fracture obtained are listed in Table 1 for all plates tested.

All plates tested were successfully perforated at each and every impact velocity, except for the 3-mm plates at V_i = 373 m/s and the 4-mm plates at V_i = 373, 408 and 448 m/s, where either partial penetration or mixed results were obtained. Plugging failure was exhibited by all plates tested with the exception of the 1-mm plates, which fell by petalling. Figure 5 shows typical plates tested exhibiting a variety of responses.

Either projectile velocity drop or its energy loss is customarily taken as the basis for analysis of ballistic test results. In the present study, however, the "specific energy loss", e, defined as the loss in projectile energy per unit thickness of target, was adopted as a more relevant parameter. Ballistic test results are summarized in Table 2, along with predicted values.

Effect of Projectile Impact Velocity

The relation between impact velocity and specific energy loss for different plate thicknesses is shown in Fig. 6. With the increase in impact velocity, the specific energy loss first decreases to a minimum, the value of which depends on the thickness and then increases. This behaviour was previously observed and discussed for a variety of target materials by many investigators, e.g. Recht and Ipson [5]; Osborn and Maj [6] and more recently by Riad [4]. At velocities near the ballistic limit, thermal effects do lower the material strength and consequently the plate resistance to penetration, whereas at higher velocities, the effect of strain rate on raising the material fracture resistance dominates

It is also of interest to note that with the increase in plate thickness, the amount of energy obsorbed, overall or specific, increases. Moreover, the initial decrease of specific energy loss for the 3 and 4-mm plates is not exhibited at the particular impact velocities considered. It is believed, however, that other values of impact velocity within the same range would have resulted in the aforementioned response.

Effect of Plate Thickness

Examination of Table 2 and Fig. 6 shows that a velocity of 544 m/s is effective in providing the projectile with energy adequate to successfully perforate available target plates at each and every impact. Being above the ballistic limits of all plates tested, this particular impact velocity fell far from the zone of mixed results, thus assuring repeatability and accuracy. Results shown in Fig. 7 represent specific energy loss with plate thickness. It is clear that both parameters are generally in direct, monotonically increasing dependence, except at V_i = 408 m/s, where the specific energy loss decreases with thickness. Predicted values of specific energy loss are also included in Figs. 6 and 7, and will be discussed subsequently.

PREDICTIONS

As has been mentioned earlier, mechanical properties of target material, including static flow strength , strain to fracture and the strain-rate sensitivity parameter c, should be input to the program. The plates were assumed to have the same average mechanical properties of = 224 MPa, = 0.251 and c = 1.0. The projectile core was 6.1 mm in diameter and 23.8 mm long.

The predicted time histories of projectile displacement and velocity as well as target resistance for an impact velocity of 544 m/s are shown in Figs. 8 to 10 for the three types of target plates exhibiting plugging failure. It is evident from these figures that the projectile exit velocity decreases, whereas the target resistance to penetration increases with plate thickness. In effect, the total time of projectile travel through the target increases. Similar results were obtained for other impact velocities. Figures 11 through 13, for instance, show the time histories for a plate of 4 mm thickness and four impact velocities.

Because of space limitation, other results will not be illustrated in a similar manner. However, predicted values of specific energy loss are contrasted with experimentally obtained values in Figs. 6 and 7. It is noted from comparison of predicted and experimental results that the agreement between both sets of values is reasonably good. Better agreement could have been achieved if the determination of the material parameter c were based on dynamic measurements of the stress-strain responses of the material, or assuming a more suitable constitutive equation to describe the material behaviour under impact loading.

It is also noted from Figs. 10 and 13 that the predicted time histories of target resistance approach zero at the moment of projectile exit. This tendency is in agreement with predictions of other penetration models, e.g. Liss, et al. [7] and in contradiction with other models such as that of Awerbuch and Bodner [8]. Experimental measurements, however, are in favour of the present model predictions [9,10].

CONCLUSIONS

The specific energy loss increases with projectile impact velocities well above the ballistic limits of tested plates. It also increases with plate thickness.

Predicted responses are in reasonable agreement with test results. Better agreement could have been achieved if the determination of plates mechanical properties were based on dynamic test results.

The Ravid-Bodner model considers localized deformation in the vicinity of the impact point. A more realistic treatment of the problem would take into account global deformation of the target as well, e.g. Shoukry [11].

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Table 1. Mechanical properties of target plates.

Plate thickness, h [mm]	Yield strength, σ_y [MPa]	Ultimate strength, σ_u [MPa]	Fracture strain, ϵ_f [mm/mm]
1	235	340	0.250
2	210	345	0.245
3	221	328	0.252
4	242	345	0.255

Table 2. Ballistic test results and predictions

Plate thick. h [mm]	Impact velocity V_i [m/s]	Residual velocity V_r [m/s]		Specific energy loss, e [J/mm]	
		Exptl.	Predict.	Exptl.	Predict.
1	372.9	320.5	---	145.2	---
	407.6	370.9	---	114.3	---
	448.3	422.3	---	90.5	---
	502.4	468.2	---	132.7	---
	544.2	505.3	---	163.3	---
	584.3	544.8	---	178.2	---
	608.3	566.5	---	196.4	---
2	372.9	247.8	291.7	155.3	107.8
	407.6	336.9	332.6	105.3	111.0
	448.3	370.9	376.2	126.8	118.9
	502.4	415.3	437.9	159.9	121.3
	544.2	448.8	484.7	189.5	122.4
	584.3	493.2	528.5	196.3	124.2
	608.3	517.0	554.8	205.5	124.5
3	372.9	---	---	---	---
	407.6	299.4	266.7	102.0	126.7
	448.3	317.3	301.6	133.7	146.7
	502.4	355.6	370.7	167.9	153.3
	544.2	386.4	421.2	195.8	158.3
	584.3	428.9	468.1	209.9	163.1
	608.3	455.6	495.9	216.6	165.5
4	372.9	---	---	---	---
	407.6	---	---	---	---
	448.3		mixed results		
	502.4	267.5	273.0	180.9	177.9
	544.2	312.5	374.3	198.5	156.1
	584.3	353.3	412.8	216.6	171.0
	608.3	385.5	449.0	221.4	168.4

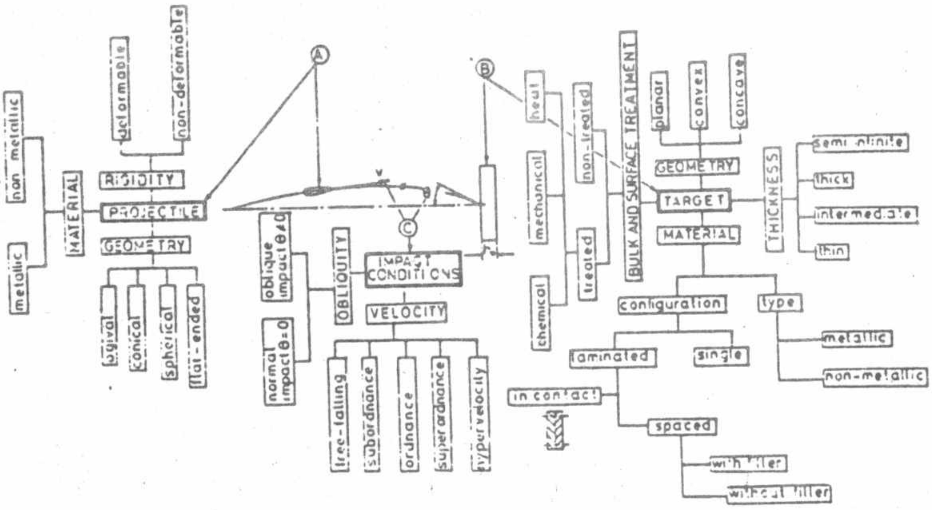


Fig. 1. Penetration parameters.

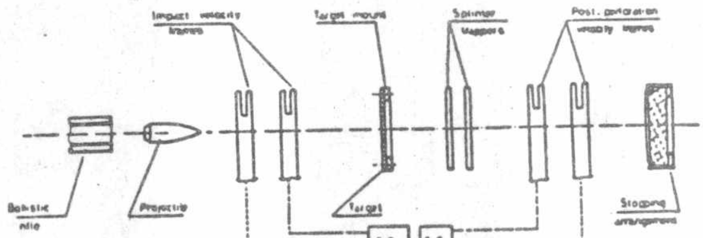


Fig. 2. Ballistic setup.

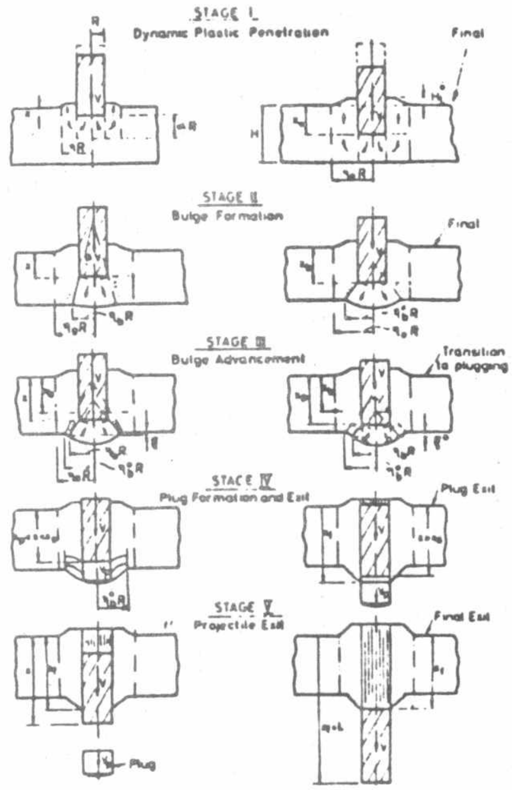


Fig. 3. Schematic of the five-stage, two-dimensional Ravid-Bodner model.

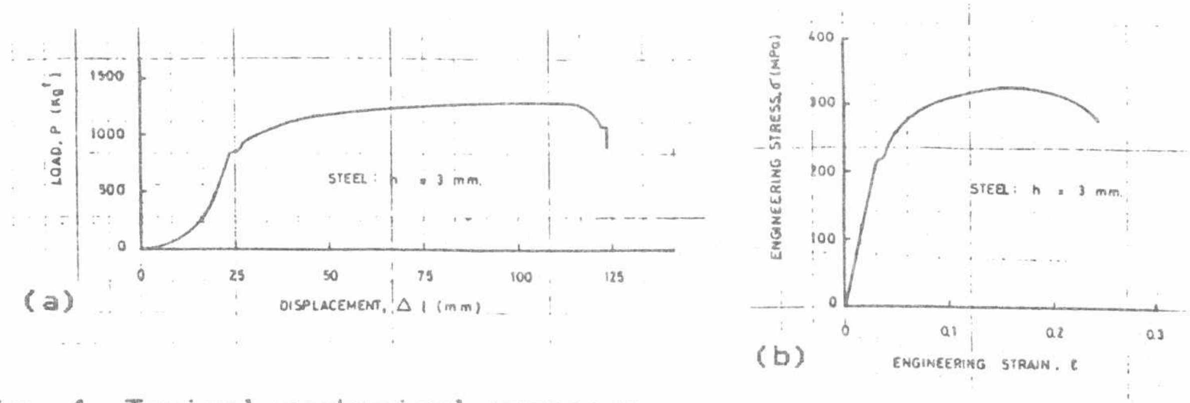


Fig. 4. Typical mechanical response of 3-mm plates:(a) Load-displacement and (b) Stress-strain

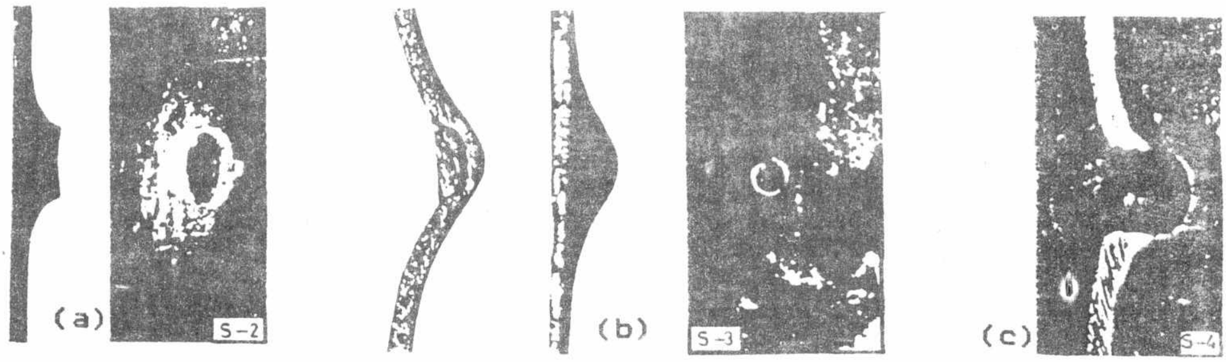


Fig. 5. Typical ballistic test results : (a) Plugging (h = 2 mm, V_i = 408 m/s), (b) Cratering (h = 3 mm, V_i = 373 m/s), and (c) Plugging (h = 4 mm, V_i = 544 m/s).

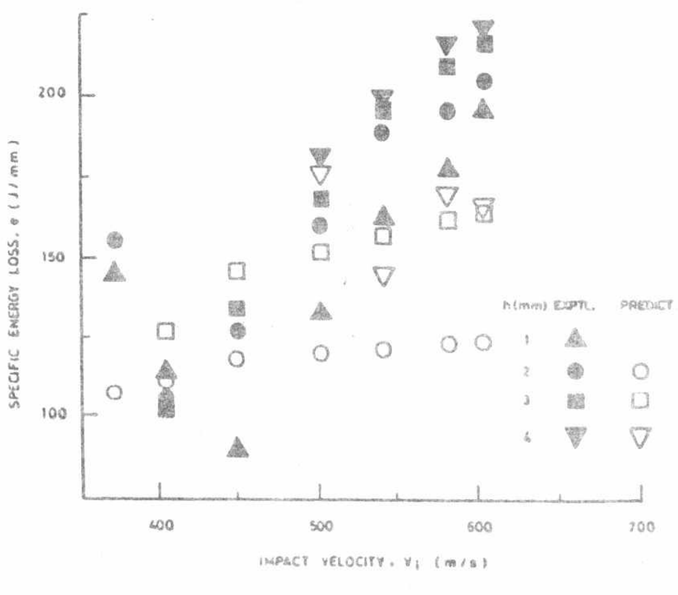


Fig. 6. Specific energy loss versus impact velocity.

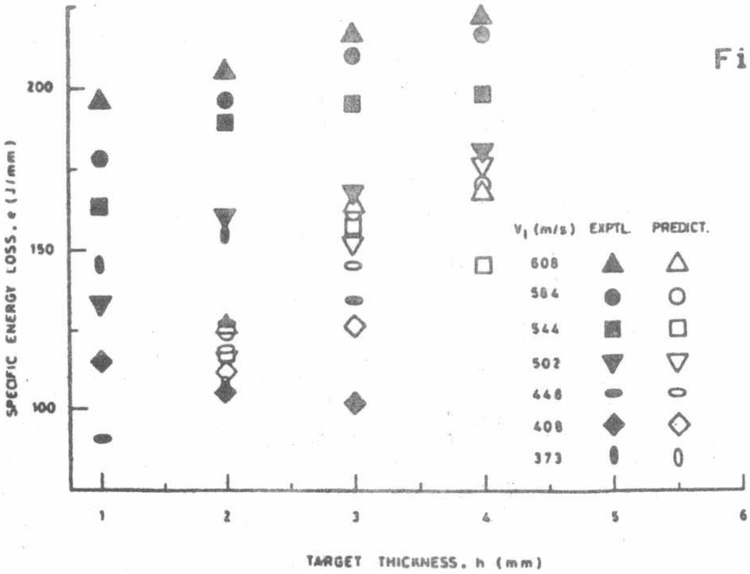
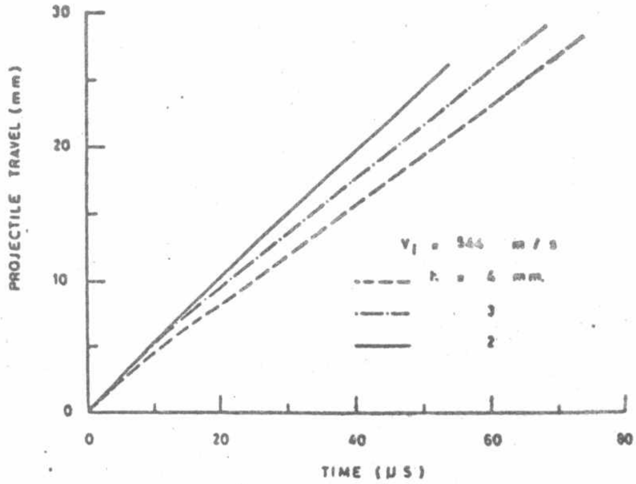


Fig. 7. Specific energy loss versus plate thickness.

Fig. 8. Time history of projectile travel at V_i = 544 m/s.



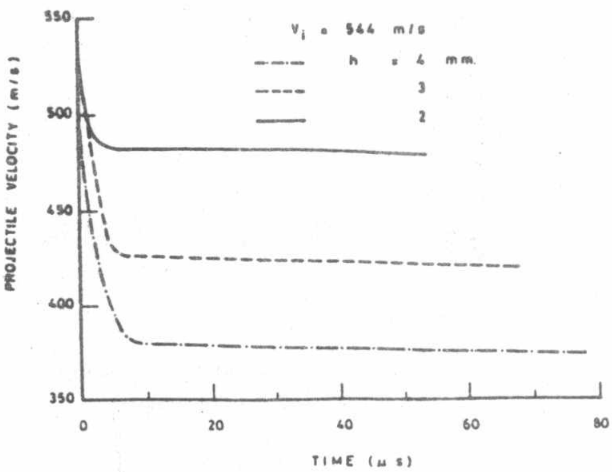


Fig. 9. Time history of projectile velocity at V_i = 544 m/s.

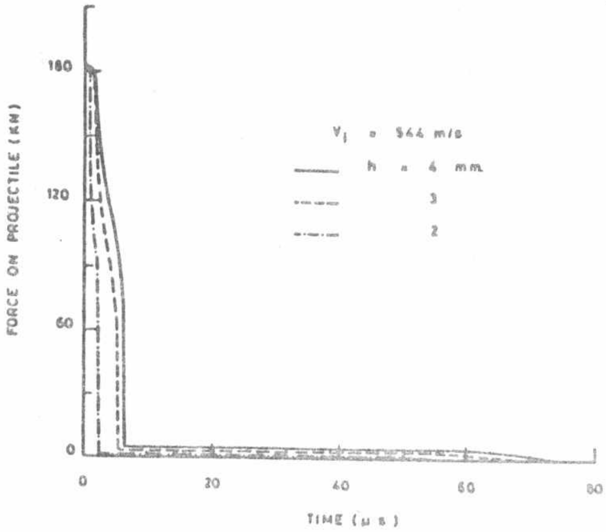


Fig. 10. Time history of target resistance at V_i = 544 m/s.

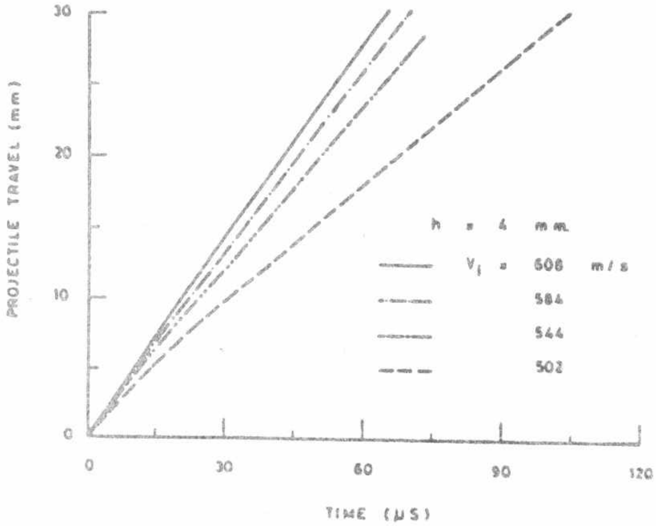


Fig. 11. Time history of projectile travel, h=4 mm.

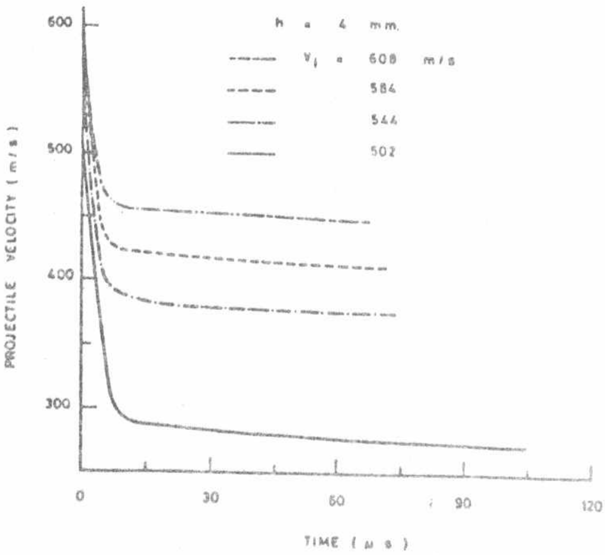


Fig. 12. Time history of projectile velocity, h=4 mm.

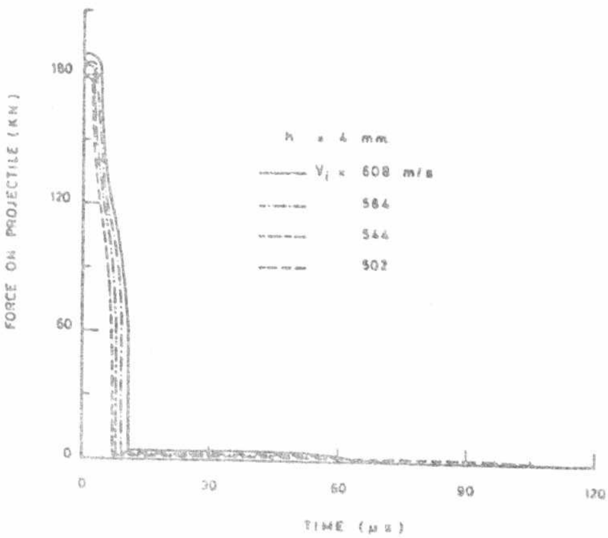


Fig. 13. Time history of target resistance, h=4 mm.