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The Effect of Material Strength on Segment Penetration Behavior

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The effects of penetrator material strength on the terminal ballistic behavior of tungsten alloy segments fired into armor plate was determined by a series of impact experiments. Three different strength tungsten alloys were machined into cylinders with an aspect ratio of 4 and were subsequently impacted into rolled homogeneous armor at 1.5 km/s. The depth of penetration and the shape of the penetrator material remaining in the penetration cavity were recorded and compared. Decreasing the penetrator material strength was observed to slightly decrease the length of residual material and the depth of penetration. The diameter of the plastically deformed residual material was observed to increase with decreasing penetrator material strength.

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1. INTRODUCTION

Segmented rod penetrator technology has emerged as a topic of interest to the terminal ballistic community due to the increase in normalized penetration performance (P/L, P being depth of penetration and L being the compact penetrator length) against rolled homogeneous armor (RHA) targets. One of the factors which has hindered the performance of segmented rod penetrators at ordnance and slightly higher velocities has been the large length of residual segment material which does not erode and must be impacted by the next subsequent segment. Even at moderately high velocities (i.e., those in the 2-km/s regime), evidence exists that the residual segment material still impedes penetration (Hohler and Stilp 1987; Raatschen et al. 1987; Orphal and Franzen 1989; Herbette 1989). Given this to be the case, it follows that segmented rod penetrator performance could be improved if the segment material was modified to reduce the residual length, but only if the same level of segment P/L is maintained. Fortunately, penetrator strength has been shown not to influence the penetration performance of tungsten alloy penetrators with length-to-diameter (L/D) ratios ranging from 10 to 15 (Meyer, Behler, Frank, and Magness 1990). However, it is unknown if this is equally true for penetrators with much lower L/D ratios.

Typical materials used for segmented rod penetrators are tungsten alloys. One approach to possibly reduce the length of tungsten residual material is to reduce the compressive strength of the segment material. Fortunately, the tungsten alloys used can be processed such that a variety of strengths can be obtained. The experimental program documented within this report used three different strength tungsten alloys. Segments were machined from each of the three alloys to have a L/D ratio of 4, and each segment was impacted into semi-infinite RHA at a velocity of 1.5 km/s. Only one segment was impacted into each target. The residual segment material was removed from the target after impact, measured, and then compared.

2. IMPACT EXPERIMENTS

A total of six shots, consisting of two shots for each of the three different strength alloys, were made in the Army Research Laboratory (ARL) high-pressure gun facility. Details of the facility are given by Baur and Nagy (1979). The gun consists of a nominal 50-mm-dia by 6-m-travel smoothbore powder gun with a large-capacity, high-pressure powder chamber. The gun empties into an impact chamber at atmospheric pressure. The target was located approximately 4.8 m from the gun muzzle. One

Table 2. Penetrator Geometries

Shot No.	1% Comp. Yield (GPa)	Mass (g)	Diameter (mm)	Length (mm)
1	0.717	385.6	19.073	76.225
2	0.717	384.8	19.058	76.175
3	1.096	384.8	19.080	76.200
4	1.096	384.5	19.065	76.200
5	1.276	385.2	19.078	75.781
6	1.276	385.2	19.058	76.035

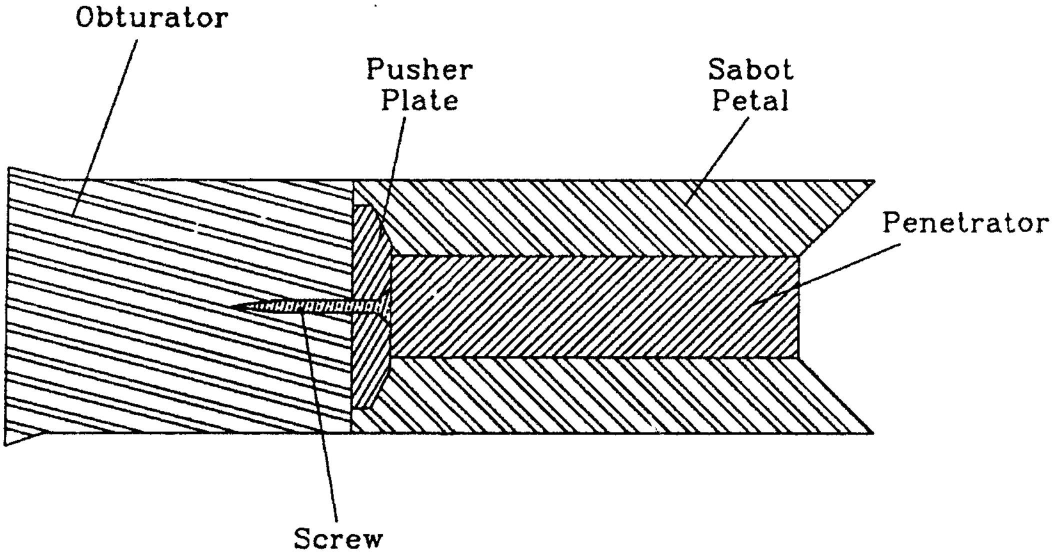

Figure 1. Cross section view of four-petal sabot.

Table 3. Results From Impact Experiments

Shot No.	1% Yield (GPa)	Velocity (km/s)	Yaw (deg)	L_R (mm)	L_H (mm)	L_S (mm)	D_H (mm)	D_C (mm)	P (mm)
1	0.717	1.509	1.5	15.69	10.91	4.78	24.13	41.38	90.18
2	0.717	1.503	1.2	16.10	11.33	4.77	23.45	41.45	88.72
3	1.096	1.514	2.7	17.42	11.62	5.80	21.29	41.21	93.04
4	1.096	1.502	1.7	17.02	13.93	3.09	23.64	41.57	93.03
5	1.276	1.501	3.4	18.36	12.34	6.02	23.54	40.94	94.04
6	1.276	1.509	0.6	18.10	11.94	6.16	22.80	40.52	95.40

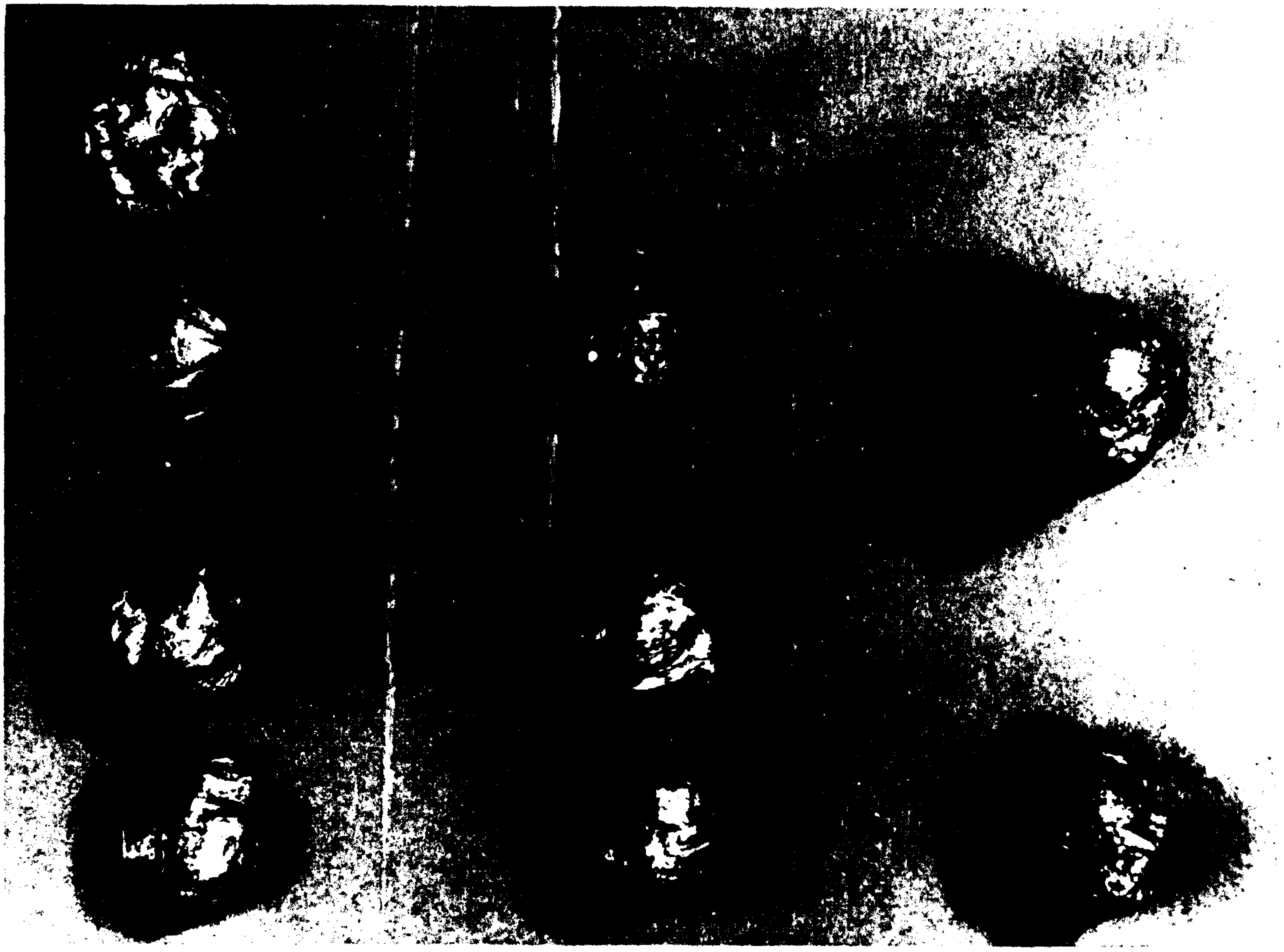

Figure 3. Recovered residual penetrators.

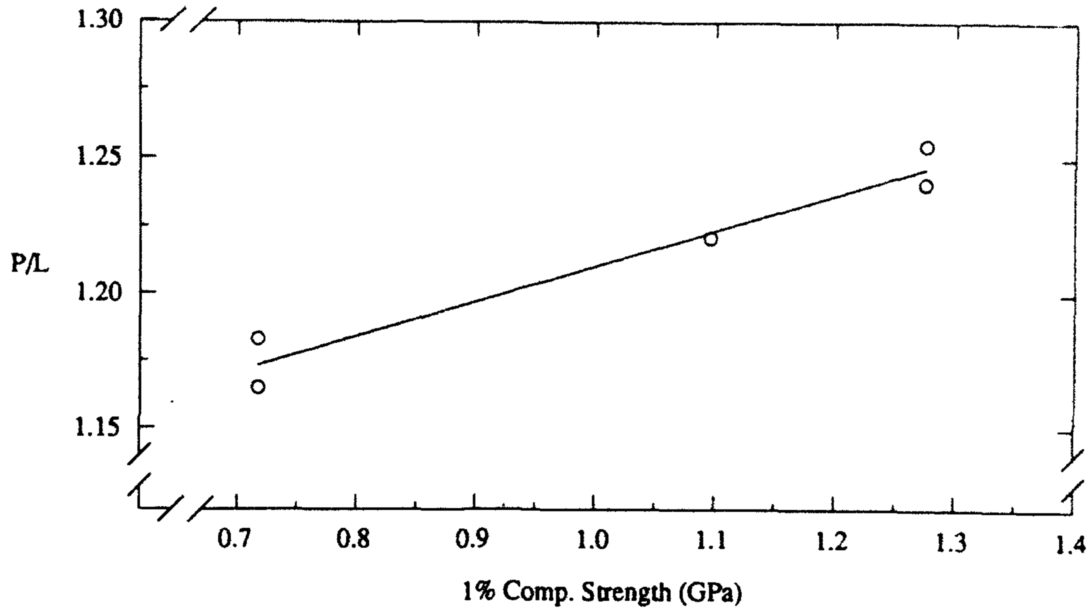

Figure 4. Normalized segment penetration vs. material strength.

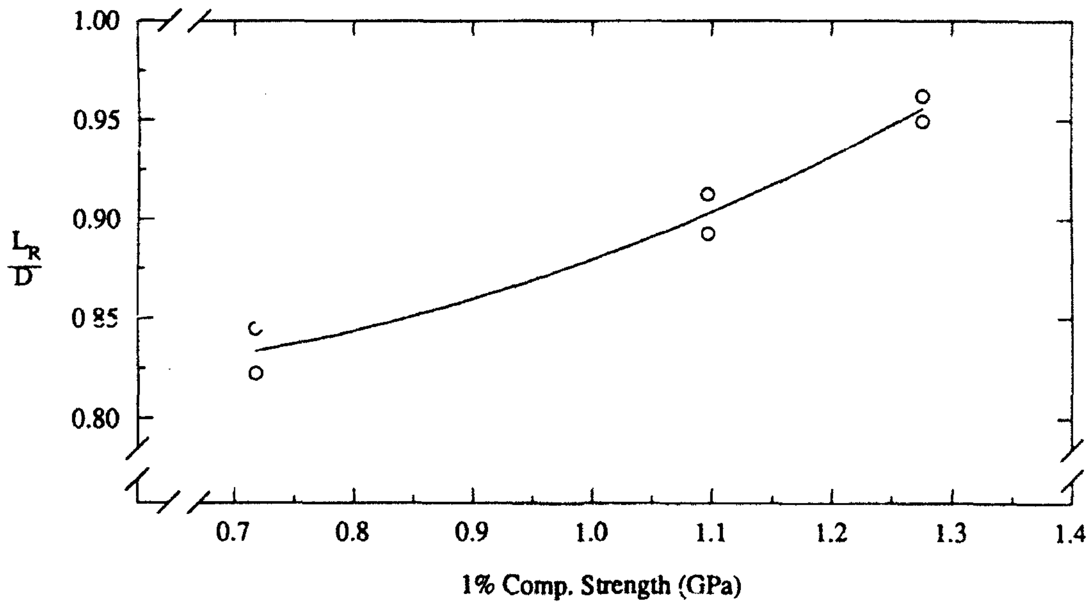

Figure 5. Normalized total residual length vs. material strength.

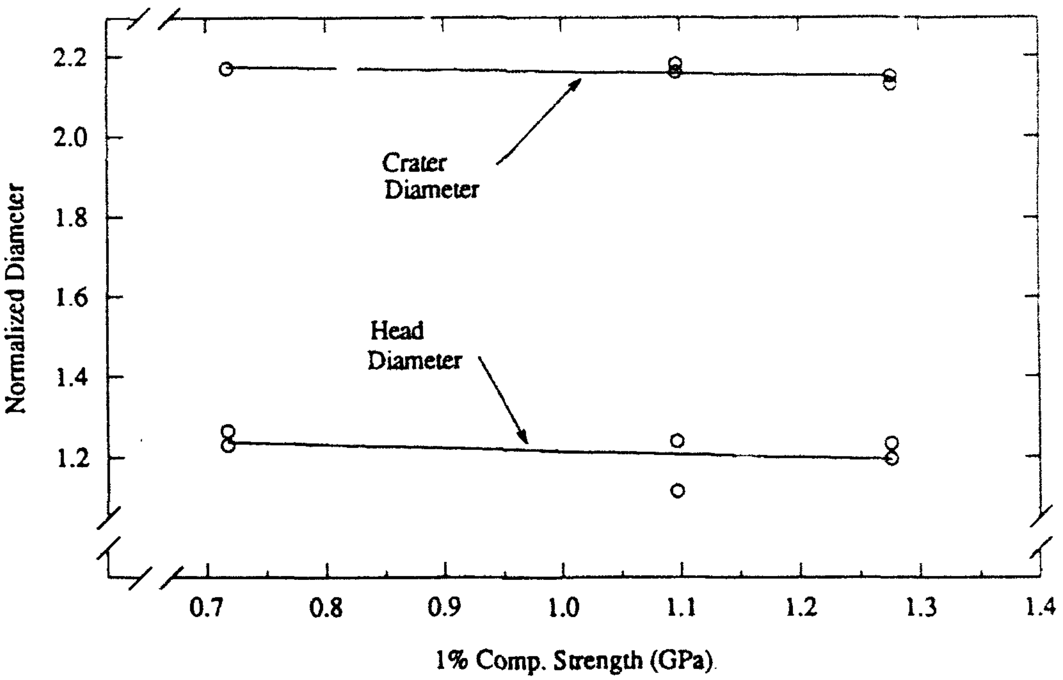

Figure 8. Normalized mushroom head diameter and impact crater diameter versus material strength.

4. CONCLUSION

The modification of segment strength had a measurable (albeit small) effect on residual material length. Decreasing material strength resulted in a slight decrease in the length of residual material, while at the same time slightly increased the diameter of the mushroom head on the residual material and the percentage of residual length in the mushroom zone. This, in turn, resulted in an increase in the crater diameter and a decrease in the depth of penetration. The effect of penetrator strength on penetration performance differs from that observed for penetrators with higher L/D ratios. This discrepancy is most likely attributable to the fact that the penetration behavior of high L/D penetrators is primarily governed by hydrodynamic forces which do not depend upon material strength, whereas the behavior of low L/D penetrators is entirely transient and does depend upon material strength. Based on the observations of this study, it appears that segments made of softer material are more prone to plastically deform their material laterally than to move deeper into the target. Although the decrease in the residual length was measurable, the magnitude was sufficiently small to preclude this approach as a viable means for substantially improving the terminal ballistic performance of segmented rod penetrators. This is reinforced by the measured decrease in individual segment P/L which accompanied the decrease in residual length.

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LIST OF SYMBOLS

D	Original segment diameter, mm
D_C	Impact crater entrance diameter, mm
D_H	Segment mushroom head diameter, mm
L	Original segment length, mm
L_H	Segment mushroom head length, mm
L_R	Total residual segment material length, mm
L_S	Shank length of residual segment material, mm
P	Depth of penetration, mm

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