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Ballistic Effectiveness of Liquid Water and Solid Water (Ice) against a Shaped Charge Jet

by Nicholas Tee and John Runyeon

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* The work outlined in this report was performed while the US Army Research Laboratory (ARL) was part of the US Army Research, Development, and Engineering Command (RDECOM). As of 31 January 2019, the organization is now part of the US Army Combat Capabilities Development Command (formerly RDECOM) and is now called CCDC Army Research Laboratory.

14. ABSTRACT

Six experiments were conducted to determine the ballistic effectiveness of liquid and solid water against a shaped charge jet. The water was evaluated at 500, 1000, and 1500 mm. The ice was evaluated at 545, 1090, and 1636 mm. Increasing the liquid water and solid water (ice) in increments provides decreasing returns in effectiveness against the shaped charge jet. The data suggest that liquid and solid water have similar protective capabilities against shaped charge jets in terms of elemental mass and space efficiencies. Since both the elemental mass efficiency and elemental space efficiency vary with target thickness, neither water nor ice can be assigned a single value to describe ballistic efficiency against a shaped charge jet.

15. SUBJECT TERMS

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1. Introduction

A previously published report regarding the ballistic effectiveness of liquid water against a shaped charge jet (Runyeon 2018) has been incorporated into this technical note. Given the similar properties of liquid water (hereinafter referred to as water) and solid water (hereinafter referred to as ice), the experimental documentation was consolidated to allow comparisons to be made.

2. Experimental Setup and Results

2.1 Ballistic Effectiveness of Water

Three experiments were conducted on 28 June 2001 at the US Army Research Laboratory* to determine the ballistic effectiveness of water against a shaped charge jet. The experimental setup is shown in Fig. 1.

The shaped charge warhead used in these experiments had a 65-mm-diameter copper liner with a 44° cone angle. At 130-mm standoff, it nominally penetrated 380 mm of rolled homogenous armor (RHA) steel. The wooden boxes were lined with plastic and filled with fresh water that had been pumped from a local well. Figure 2 is a typical photograph of this procedure. Figure 3 is a photograph of a typical experimental setup. Figure 4 is a photograph of typical postexperimental debris. Table 1 summarizes the experimental results.

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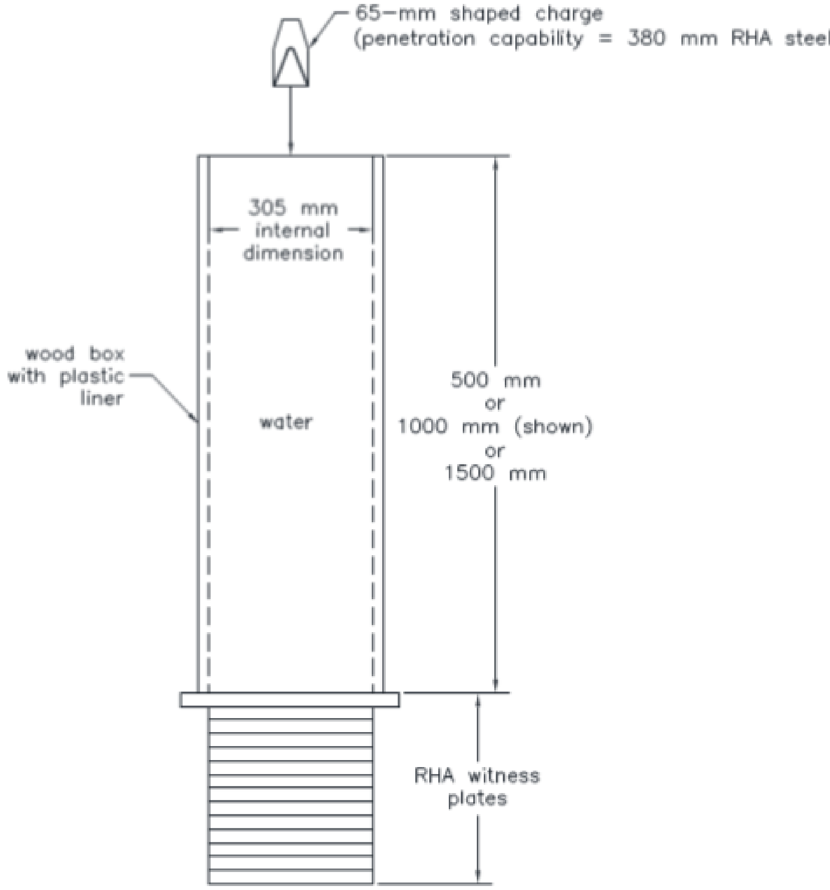

Fig. 1 Experimental setup for water

Fig. 2 Filling target with 500 mm of water

Fig. 3 Typical experimental setup. Target with 1000 mm of water is shown. The wooden target assembly has a hole cut in the top so the first material impacted by the shaped charge jet is water.

Fig. 4 Typical postexperimental debris. Debris from target with 1000 mm of water is shown. The jet stopped in witness Plate 3.

Table 1 Summary of experimental results for water

Depth of water (mm)	**Penetration into RHA witness plate (mm)**
0	380 (baseline data)
500	128
1000	56
1500	32

2.2 Ballistic Effectiveness of Ice

Three additional experiments were conducted on 28–29 January 2019 to determine the ballistic effectiveness of ice against a shaped charge jet. As a continuation of the experimentation done on water in 2001, the setup was kept as similar as possible to compare the ballistic effectiveness of water and ice.

The experimental setup is shown in Figs. 5 and 6. Based on typical ice having a density of approximately 0.917 g/cm^3, each thickness of ice was increased to maintain the same areal density as the original targets of water. Shown in Fig. 7, plastic-lined plywood boxes were filled with fresh water and kept at –50 °F until completely frozen. To simplify the setup and accelerate the freezing process, the ice was frozen and placed horizontally. A chainsaw was used to cut the ice to the correct thickness and create a flat surface, perpendicular to the shot line. The plywood and plastic were removed from the ice before each experiment. The diameter and cone angle of the shaped charge warheads used in these experiments were identical to those used against the water. The standoff distance was kept constant at 130 mm. The baseline nominal penetration into RHA remained at 380 mm. Figure 8 is a photograph of typical postexperimental debris. Table 2 summarizes the results for each thickness of ice.

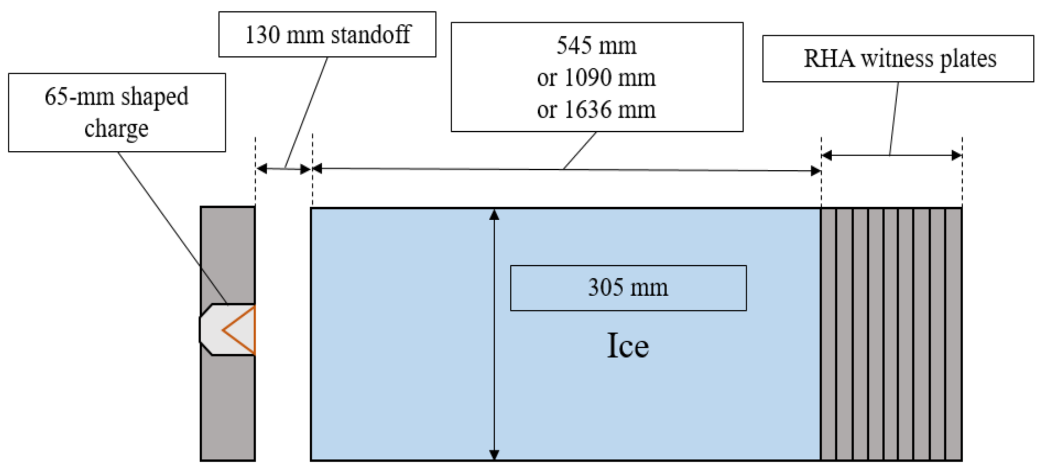

Fig. 5 Experimental setup for ice

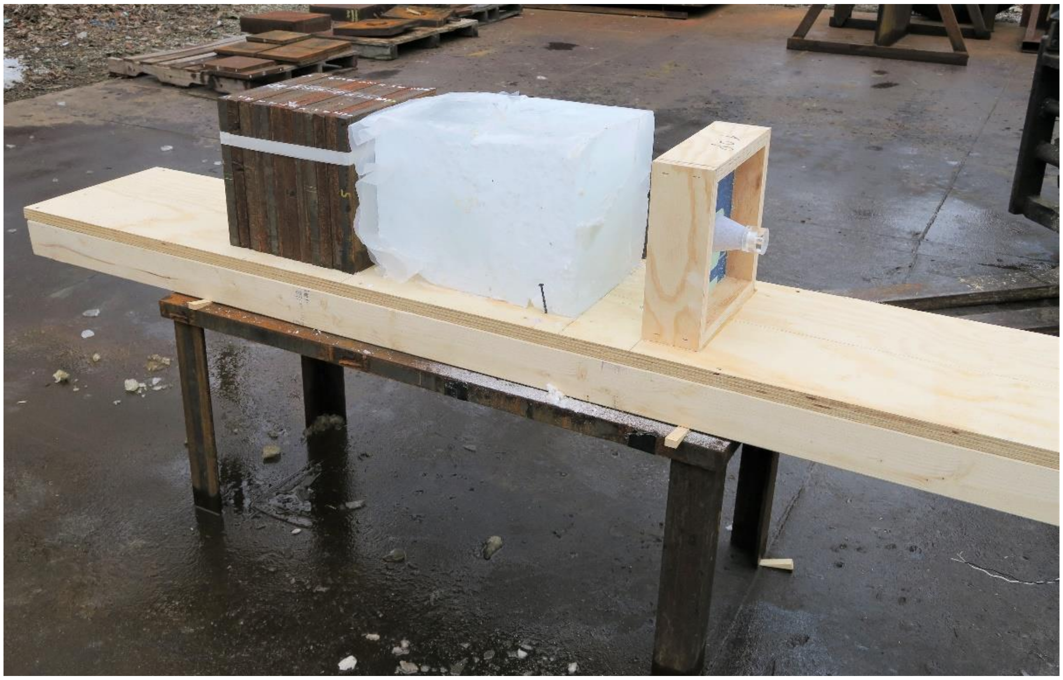

Fig. 6 Typical experimental setup showing a 545-mm ice target

Fig. 7 Typical box used to hold and freeze the water. The 1090-mm box is shown.

Fig. 8 Typical postexperimental debris. Witness plates from 1090-mm ice target are shown. The jet stopped in witness Plate 2 (W2).

Table 2 Summary of experimental results for ice

Ice thickness (mm)	Penetration into RHA witness plate (mm)
0	380 (baseline data)
545	147
1090	36
1636	0 (stopped in ice, did not reach witness plate)

3. Discussion and Conclusion

Shown in Tables 1 and 2, the data suggest that water and ice have similar protective capabilities against shaped charge jets. The findings of this research are limited by the absence of repetition for each experiment. Shaped charges have round-to-round variation and only one data point exists for each condition.

Table 3 is a summary of the experimental results including elemental mass efficiency (e_m) and elemental space efficiency (e_s). Note that the shaped charge jet did not perforate the 1636-mm ice target, so the residual penetration could not be measured. Thus, the actual e_m and e_s for 1636 mm of ice is potentially higher than the calculated value. Increasing the water in 500-mm increments showed decreasing returns in effectiveness against the jet. Increasing the thickness of ice showed similarly decreasing returns. Since both the e_m and e_s vary with target thickness, neither water nor ice can be assigned a single value to describe ballistic efficiency against a shaped charge jet.

Table 3 Summary of results including elemental mass and space efficiency

Material	Thickness (mm)	Penetration into RHA witness plate (mm)	e_m	e_s	$e_m \times e_s$
RHA		380	1	1	1
water	500	128	3.9	0.50	2.0
water	1000	56	2.6	0.32	0.83
water	1500	32	1.8	0.23	0.41
ice	545	147	3.6	0.43	1.5
ice	1090	36	2.7	0.32	0.86
ice	1636	0	2.0	0.23	0.46

The e_m and e_s calculations:

- e_m = (RHA penetration capability of the shaped charge minus residual penetration into RHA witness)/areal density of target expressed in terms of RHA equivalent.
- e_s = (RHA penetration capability of the shaped charge minus residual penetration into RHA witness)/thickness of target.
- For the experiment with 500 mm of water, 500 mm of water has the equivalent areal density of 64 mm of RHA steel. Therefore, e_m = (380-mm RHA penetration capability minus 128-mm RHA residual penetration)/ 64-mm RHA equivalent = 252/64 = 3.9. The e_s = (380-mm RHA penetration capability minus 128-mm RHA residual penetration)/500-mm target thickness = 252/500 = 0.50.
- For the experiment with 1000 mm of water, e_m = (380-mm RHA penetration capability minus 56-mm RHA residual penetration)/127-mm RHA equivalent = 324/127 = 2.6. The e_s = (380-mm RHA penetration capability minus 56-mm RHA residual penetration)/1000-mm target thickness = 324/1000 = 0.32.

- For the experiment with 1500 mm of water, e_m = (380-mm RHA penetration capability minus 32-mm RHA residual penetration)/191-mm RHA equivalent = 348/191 = 1.8. The e_s = (380-mm RHA penetration capability minus 32-mm RHA residual penetration)/1500-mm target thickness = 348/1500 = 0.23.

- For the experiment with 545 mm of ice, e_m = (380-mm RHA penetration capability minus 147-mm RHA residual penetration)/64-mm RHA equivalent = 233/64 = 3.6. The e_s = (380-mm RHA penetration capability minus 147-mm RHA residual penetration)/545-mm target thickness = 233/545 = 0.43.

- For the experiment with 1090 mm of ice, e_m = (380-mm RHA penetration capability minus 36-mm RHA residual penetration)/127-mm RHA equivalent = 344/127 = 2.7. The e_s = (380-mm RHA penetration capability minus 36-mm RHA residual penetration)/1090-mm target thickness = 344/1090 = 0.32.

- For the experiment with 1636 mm of ice, e_m = (380-mm RHA penetration capability minus 0-mm RHA residual penetration)/191-mm RHA equivalent = 380/191 = 2.0. The e_s = (380-mm RHA penetration capability minus 0-mm RHA residual penetration)/1636-mm target thickness = 380/1636 = 0.23.

4. References

Runyeon J. Ballistic effectiveness of water against a shaped charge jet. Aberdeen Proving Ground (MD): Army Research Laboratory (US); 2018 Dec. Report No.: ARL-TN-0932.

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