Defence Research and Development Canada
Recherche et développement pour la défense Canada

RHA steel variations and their effects on ballistic protection

Grant W.J. McIntosh
DRDC Valcartier

Defence R&D Canada – Valcartier

Technical Memorandum
DRDC Valcartier TM 2011-533
April 2012

Canada

RHA steel variations and their effects on ballistic protection

Grant W.J. McIntosh
DRDC Valcartier

Defence R&D Canada – Valcartier

Technical Memorandum
DRDC Valcartier TM 2011-533
April 2012

Principal Author

Original signed by Grant W.J. McIntosh

Grant W.J. McIntosh

Approved by

Original signed by Dennis Nandlall

Dennis Nandlall

Head / Weapons Effects Section

Approved for release by

Original signed by Christian Carrier

Christian Carrier

Chief Scientist DRDC Valcartier

Abstract

A short study was undertaken to see if the ballistic performance of ¼" RHA steel plates can vary from batch-to-batch. Several random samples from the DRDC Valcartier stock were tested in a V50 test using a 5.56-mm Bofors armour piercing round. Small but statistically significant variations in the V50 were found even though all the samples were within the accepted standards for RHA.

Résumé

Une investigation courte a été entreprise a voir si la performance balistique d'un acier de blindage (RHA) ¼ de pouce d'épaisseur peut varier de lot à lot. Des échantillons choisis au hasard du stock du RDDC Valcartier ont été testées pour leur V50 contre une balle 5.56 mm Bofors AP. De petites, mais statistiquement significatives, variations ont été observées malgré le fait que tous les échantillons respectaient les normes pour le RHA.

This page intentionally left blank.

Executive summary

RHA steel variations and their effects on ballistic protection:

Grant W.J. McIntosh; DRDC Valcartier TM 2011-533; Defence R&D Canada – Valcartier; April 2012.

Introduction or background: From time to time, a question arises as to whether or not variations in RHA steel characteristics have an effect on its performance in actual use. Variations in the properties are expected and indeed are allowed by the RHA mil standard MIL-A-12560H (MR). A short study was undertaken to see if the ballistic performance of ¼” RHA steel plates can vary from batch-to-batch. Several random samples from the DRDC Valcartier stock were tested in a V50 test using a 5.56-mm Bofors armour piercing round.

Results: Small but statistically significant variations in the V50 were found even though all the samples were within the accepted standards for RHA.

Significance: Any critical applications using RHA may require more extensive testing for each RHA plate used.

Future plans: No future work is envisaged other than reminding armor designers that critical designs require more precise data.

Sommaire

RHA steel variations and their effects on ballistic protection:

Grant W.J. McIntosh ; DRDC Valcartier TM 2011-533 ; R & D pour la défense Canada – Valcartier; avril 2012.

Introduction ou contexte : De temps en temps, on pose la question si les variations dans les propretés d'acier RHA peuvent changer la performance balistique dans une application pratique. Des variations sont anticipées et sont même permises par les normes militaires MIL-A-12560H (MR). Une étude courte a été entreprise pour voir si la performance balistique des plaques d'acier RHA ¼ de pouce d'épaisseur peut varier de lot à lot. Plusieurs échantillons de RHA choisis au hasard du stock de RDDC Valcartier ont été testés pour leur V50 en utilisant une balle 5.56mm Bofors AP.

Résultats : De petites mais statistiquement significatives variations dans la V50 ont été observées malgré le fait que les échantillons respectaient les normes pour le RHA.

Importance : Une application critique qui utilise un acier RHA peut nécessiter une évaluation plus poussée de chaque plaque de RHA utilisée.

Perspectives : Aucun travail futur n'est prévu à part d'un rappel aux ingénieurs en blindage qu'une conception critique exige des données plus précises

Table of contents

Abstract …….. i
Résumé …..... i
Executive summary iii
Sommaire iv
Table of contents v
List of figures vi
List of tables vii
Acknowledgements viii
1 Introduction.. 1
2 Experimental setup 2
3 Results and Discussion 3
4 Conclusions... 11
References 12
List of symbols/abbreviations/acronyms/initialisms 13

List of figures

Figure 1 Setup for a test showing the gun (left), time-of-flight velocity probes and sample to be tested with a witness plate (right) ... 2

Figure 2 V50 as a function of Brinell hardness(data from Table 2) ... 9

List of tables

Table 1: Results of all the shots 7
Table 2 : Summary of Hardnesses and V50’s 8
Table 3 Student’s t-test correlations (2-tailed P values) 10

Acknowledgements

The able technical abilities of M. Michel Girard are gratefully acknowledged.

1 Introduction

From time to time, a question arises as to whether or not variations in RHA steel characteristics have an effect on its performance in actual use. Variations in the properties are expected and indeed are allowed by the RHA mil standard MIL-A-12560H (MR). For example, for a ¼” thick RHA plate, the Brinell hardness can vary between 341 and 388. For the same plate, the only specified ballistic limit (for a 0.30 calibre AP round) is a minimum value of is 486.5 m/s, a higher limit implicitly being acceptable (except for class 3 armour for use in the proof and acceptance testing of armor defeating ammunition where a maximum of 43 m/s over the minimum limit is allowed). Under normal engineering conditions, there is usually enough over-design that such variations can be tolerated. Within a research environment, precise measurements of armour performance can be made but any observed differences may or may not be really due to variations in the steel properties from lot to lot. In this small study, several RHA samples chosen at random from DRDC Valcartier’s stock were tested both for hardness and then V50 performance. The results are then analysed to see if any observed variations are real, at least in a statistical sense.

2 Experimental setup

A total of 17 samples of RHA steel armour plates were chosen at random from DRDC Valcartier's stockpile of RHA armour and tested for hardness using a Brinell tester. The samples were then tested using a Bofors 5.56 mm armour piercing round (M995) to determine the V50. The bullets impacted normally on the plates and partial (P) or complete (C) perforations were noted. The velocity of impact was varied so that three partial and 3 complete perforations were obtained within a 40 m/s range. The experimental arrangement is shown in Figure 1.

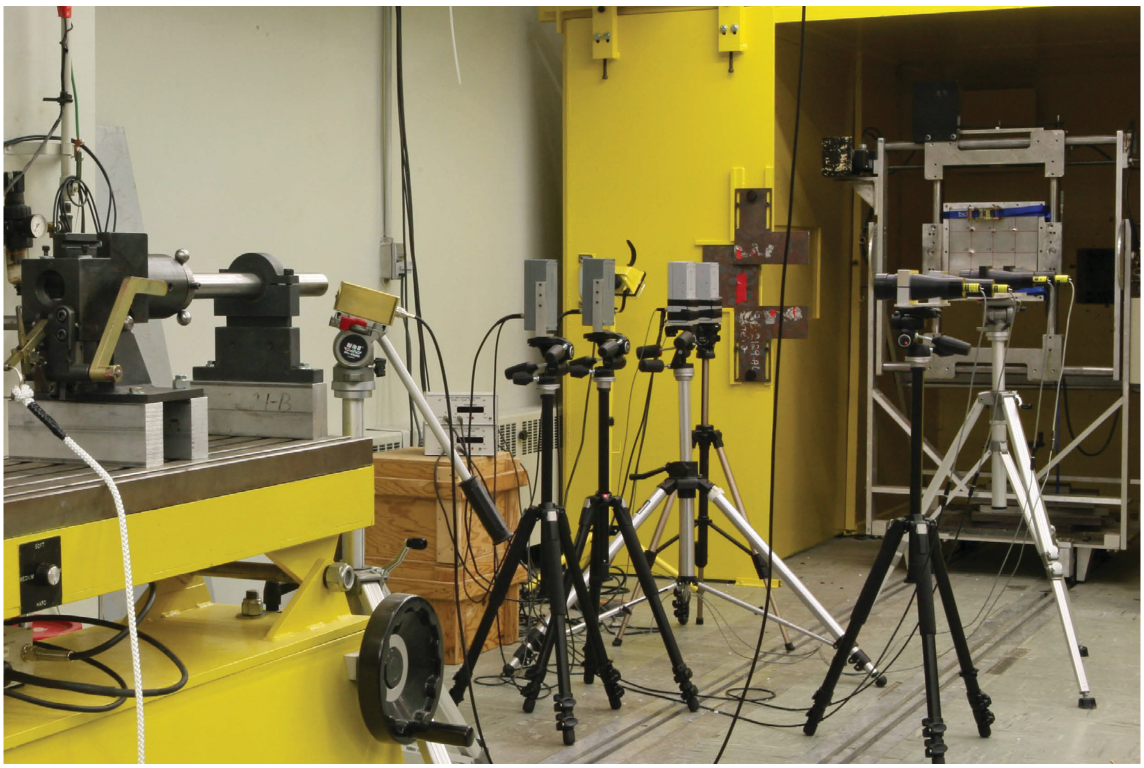

Figure 1 Setup for a test showing the gun (left), time-of-flight velocity probes and sample to be tested with a witness plate (right)

3 Results and Discussion

The results of all the hardness and ballistic impact tests are given in Table1. Each shot is summarised with a plate number, the 5.56mm AP round impact velocity, the observation of complete perforation or partial/no perforation, the black powder charge loaded to give the velocity observed and the plate hardness.

Plate number	Shot number	Impact velocity(m/s)	Complete (C) or Partial (P) perforation	Powder charge (grains)	Hardness (Brinell)
D1	1	538	C	10	341 BHN
	2	533.9	P	9.9	
	3	546.5	C	9.9	
	4	462	P	?	
	5	496	P	10	
	6	549.7	C	10.4	
	7	529.7	P	10.2	
	8	562.7	C	10.2	
	9	453.9	P	10.1	
	10	522	P	10.2	
D2	1	460.5	P	10.2	341 BHN
	2	527.2	P	10.2	
	3	478	P	10.2	
	4	570	C	10.4	
	5	648	C	10.5	
	6	483	P	8.44	
	7	587.7	C	9	
	8	502	P	8.8	
	9	531.9	P	8.8	
	10	530.7	P	8.9	
	11	565.9	C	8.96	
	12	534.4	P	8.94	
	13	545.3	C	8.96	
	14	540.1	C	8.96	
E1	1	542.9	C	8.96	341 BHN
	2	469	P	8.96	

	3	549.3	C	8.96	
	4	581	C	8.96	
	5	529.7	P	8.94	
	6	570.9	C	8.94	
	7	537.5	P	8.92	
	8	517.4	P	8.92	
	9	570	C	8.96	
	10	547.2	C	8.94	
E2	1	529.6	P	8.96	341 BHN
	2	514.2	P	8.96	
	3	542.1	P	9	
	4	555.6	C	9.02	
	5	567	C	9.02	
	6	543.6	C	9.02	
	7	538	P	8.98	
G1	1	558.7	C	8.5	341 BHN
	2	547.6	C	8.42	
	3	539.5	C	8.36	
	4	538.3	C	8.32	
	5	536.2	P	8.22	
	6	534.8	P	8.18	
	7	538.4	P	8.2	
G2	1	539.1	C	8.96	341 BHN
	2	562.5	C	8.96	
	3	576.3	C	8.92	
	4	576.2	C	8.9	
	5	497.6	P	8.86	
	6	488.9	P	8.92	
	7	555	C	8.96	
	8	550.1	C	8.94	
	9	555.9	C	8.92	
	10	574.5	C	8.88	
	11	541.7	C	8.8	
	12	496.9	P	8.78	
	13	545.4	C	8.78	
	14	537.9	P	8.78	
	15	545.9	C	8.78	
	16	549	C	8.76	
	17	553.4	C	8.74	
	18	560.4	C	8.74	
	19	554.5	C	8.7	
	20	531.9	P	8.6	
	21	555	C	8.6	
	22	552	C	8.5	

	23	523.8	P	8.54	
H1	1	510.9	P	8.6	380 BHN
	2	530.3	P	8.7	
	3	542	P	8.8	
	4	552.3	C	8.8	
	5	545.8	P	8.8	
	6	560.2	C	8.8	
	7	561.8	C	8.8	
	8	555.4	C	8.7	
H2	1	550.3	P	8.54	388 BHN
	2	542.3	P	8.54	
	3	543.2	P	8.56	
	4	545.2	P	8.6	
	5	530.2	P	8.66	
	6	559.8	C	8.8	
	7	557	C	8.8	
	8	528.4	P	8.84	
	9	576.3	C	8.84	
	10	545.6	P	8.8	
	11	549.1	P	8.82	
	12	558.5	C	8.84	
I1	1	571.7	C	8.7	341 BHN
	2	545.3	C	8.6	
	3	543.3	C	8.5	
	4	411	P	8.44	
	5	546.7	C	8.5	
	6	542.5	C	8.46	
	7	533	P	8.44	
	8	546	C	8.44	
	9	521.9	P	8.4	
	10	531.8	P	8.42	
I2	1	541.9	P	8.44	343 BHN
	2	534.6	P	8.44	
	3	541	P	8.46	
	4	541.2	C	8.48	
	5	549.4	C	8.5	
	6	532	P	8.5	
	7	550.9	C	8.54	
J1	1	518.7	P	8.84	395 BHN
	2	558.8	C	8.92	
	3	557.86	C	8.9	
	4	543.7	P	8.82	
	5	526.7	P	8.82	
	6	572.2	C	8.8	

	7	565.6	C	8.82	
	8	564.5	C	8.74	
	9	563	C	8.7	
	10	545.1	P	8.6	
	11	556.1	C	8.6	
	12	544.9	P	8.6	
J2	1	563.7	C	8.6	388 BHN
	2	526.7	P	8.6	
	3	559.5	C	8.62	
	4	529.4	P	8.6	
	5	559.9	C	8.62	
	6	558.7	C	8.6	
	7	576.6	C	8.58	
	8	559.7	C	8.54	
	9	543.5	P	8.5	
	10	521.1	P	8.5	
	11	544.7	P	8.52	
	12	541.3	P	8.52	
K1	1	541.2	P	8.4	341 BHN
	2	519.9	P	8.5	
	3	558.5	P	8.56	
	4	557.2	P	8.56	
	5	566.3	C	8.6	
	6	560.8	C	8.6	
	7	563.3	C	8.62	
K2	1	538.2	P	8.5	341 BHN
	2	558.6	C	8.6	
	3	530.3	P	8.56	
	4	548.8	P	8.5	
	5	538.6	P	8.6	
	6	554.4	P	8.7	
	7	555.8	C	8.76	
	8	572.8	C	8.8	
L1	1	533.6	P	8.52	356 BHN
	2	563.2	P	8.56	
	3	566.1	P	8.56	
	4	549.3	P	8.6	
	5	551	P	8.62	
	6	526.8	P	8.66	
	7	563	P	8.7	
	8	550.7	P	8.74	
	9	554.6	P	8.8	
	10	565.8	C	8.86	
	11	572.3	C	8.9	

	12	558	P	8.9	
	13	568.9	C	8.92	
M1	1	558.5	C	8.72	347 BHN
	2	545.4	P	8.7	
	3	550.3	P	8.72	
	4	559.8	C	8.74	
	5	558.5	C	8.7	
	6	490	P	8.66	
	7	555.5	P	8.7	
N1	1	536.6	P	8.7	341 BHN
	2	564.79	C	8.72	
	3	510.2	P	8.7	
	4	560.6	C	8.7	
	5	570.6	C	8.7	
	6	574.9	C	8.66	
	7	549.8	C	8.6	
	8	566.2	C	8.62	
	9	566.8	C	8.56	
	10	555.4	C	8.5	
	11	547.5	C	8.5	
	12	550.8	C	8.46	
	13	556.7	C	8.42	
	14	562.7	C	8.34	
	15	538.2	C	8.2	
	16	524.7	P	8.14	
	17	508.1	P	8.14	
	18	544.4	C	8.16	
	19	508.4	P	8.14	
	20	529.8	C	8.16	

Table 1: Results of all the shots

The results from Table 1 can be analysed in a simple fashion. For each series of tests, the three lowest C values and the three highest P values are averaged to generate the V50 average and standard deviation. The variation of impact velocities used was such that the difference between the highest and lowest of the 6 values averaged was less than 40 m/s since STANAG 2920 specifies 3 pass / 3 fail within this limit. The final results are shown in Table 2. As a first try at understanding the results, the V50 versus hardness was plotted and shown in Figure 2. There is no obvious correlation.

Plate number	Brinell hardness	V50 (m/s) (with a standard deviation)
D1	341	536.6 +/- 10.4
D2	341	541.4 +/- 13.2
E1	341	537.2 +/- 12.1
E2	341	545.9 +/- 13.3
G1	341	539.1 +/- 4.5
G2	341	536.6 +/- 7.7
H1	380	547.6 +/- 10.7
H2	388	553.4 +/- 5.8
I1	341	536.3 +/- 9.0
I2	343	543.2 +/- 6.0
J1	395	551.1 +/- 7.2
J2	388	551.2 +/- 8.9
K1	341	557.9 +/- 8.8
K2	341	554.8 +/- 11.3
L1	356	566.6 +/- 3.6
M1	347	554.7 +/- 5.7
N1	341	530.7 +/- 12.1

Table 2 : Summary of Hardnesses and V50's

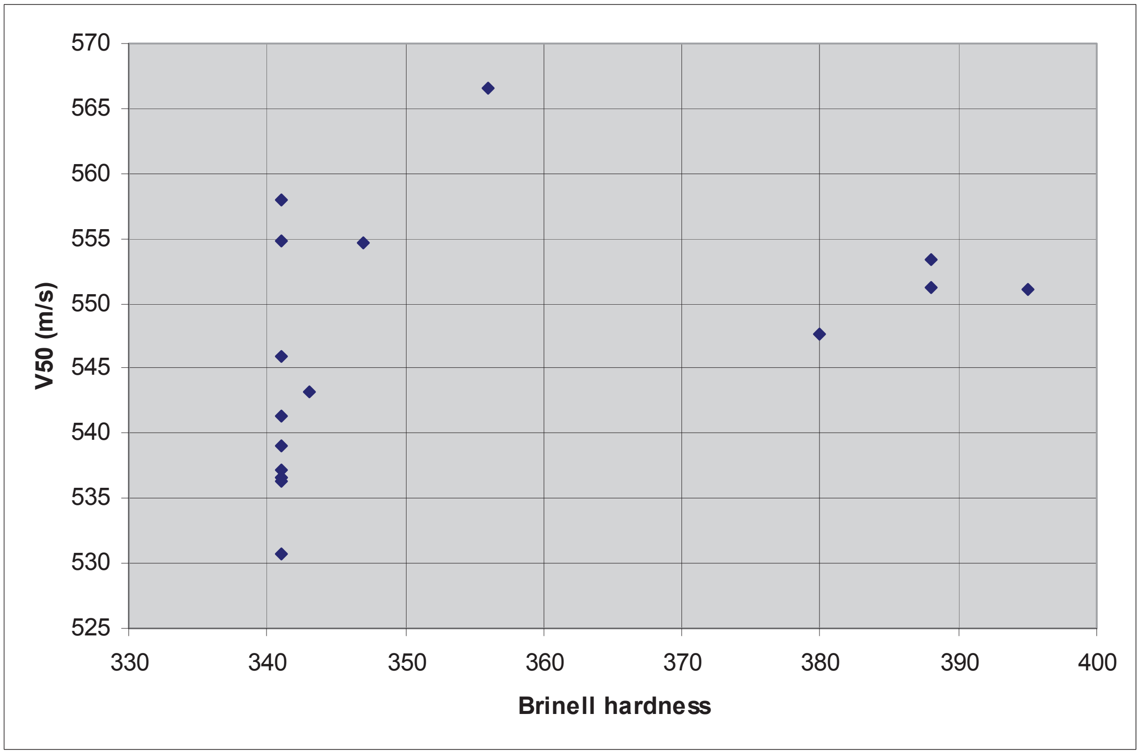

Figure 2 V50 as a function of Brinell hardness (data from Table 2)

Since all the samples fall or nearly fall within the RHA hardness range specified by the mil standard, it is assumed they are representative of the variations one would expect to find from lot to lot. The V50's that were measured are then compared to see if they are statistically different or not. This was done using Student's t-test (Ref. 1) which evaluates the probability that two values are the same. A matrix of comparisons was set up and is presented in Table 3. For example, the P value between the V50's observed in trials N1 and L1 is less than 0.000 whereas for trials G1 and D2 it is 0.69, a P value less than 0.05 suggesting a statistically significant difference. The actual differences in V50 are small (less than 7%). In a number of cases, the small differences are indeed statistically significant.

	D1	D2	E1	E2	G1	G2	H1	H2	I1	I2	J1	J2	K1	K2	L1	M1	N1
D1	X																
D2	0.5	X															
E1	0.92	0.59	X														
E2	0.21	0.57	0.27	X													
G1	0.72	0.69	0.74	0.26	X												
G2	1.0	0.46	0.91	0.17	0.49	X											
H1	0.1	0.39	0.15	0.81	0.10	0.068	X										
H2	0.006	0.069	0.015	0.23	0.001	0.002	0.27	X									
I1	0.96	0.45	0.87	0.17	0.51	0.95	0.076	0.003	X								
I2	0.21	0.77	0.31	0.66	0.21	0.13	0.40	0.013	0.15	X							
J1	0.019	0.15	0.037	0.42	0.006	0.007	0.52	0.56	0.010	0.066	X						
J2	0.026	0.16	0.047	0.44	0.014	0.012	0.54	0.62	0.016	0.098	0.98	X					
K1	0.003	0.029	0.007	0.095	0.001	0.001	0.099	0.32	0.002	0.007	0.17	0.22	X				
K2	0.016	0.088	0.027	0.24	0.010	0.009	0.28	0.79	0.011	0.051	0.51	0.55	0.61	X			
L1	0.000	0.001	0.000	0.004	0.000	0.000	0.002	0.001	0.000	0.000	0.001	0.003	0.049	0.035	X		
M1	0.004	0.047	0.001	0.17	0.000	0.001	0.18	0.70	0.0017	0.007	0.36	0.44	0.47	0.98	0.002	X	
N1	0.39	0.17	0.37	0.065	0.14	0.34	0.028	0.002	0.38	0.047	0.005	0.008	0.001	0.005	0.000	0.001	X

Table 3 Student's t-test correlations (2-tailed P values)

4 Conclusions

The ballistics properties of RHA steels do vary from batch to batch. The variations in the V50 are small (less than 7%) but are statistically significant. In critical applications (e.g. laboratory scale experiments seeking incremental improvements in some ballistic parameter), careful characterisation of the RHA used will have to be done so that these variations do not have an impact on the desired outcome. For most practical armour purposes, these variations can be neglected.

References

[1] Press, William H. et al., "Numerical Recipes – the Art of Scientific Computing", Cambridge University Press, 1986, p. 464-469

.

List of symbols/abbreviations/acronyms/initialisms

DND	Department of National Defence
DRDC	Defence Research & Development Canada
RHA	Rolled Homogeneous Armour steel
V50	Velocity of bullet impact at which the probability of perforation of an armour plate is 50%

This page intentionally left blank.

DOCUMENT CONTROL DATA

(Security classification of title, body of abstract and indexing annotation must be entered when the overall document is classified)

1. ORIGINATOR (The name and address of the organization preparing the document. Organizations for whom the document was prepared, e.g. Centre sponsoring a contractor's report, or tasking agency, are entered in section 8.) Defence R&D Canada – Valcartier 2459 Pie-XI Blvd North Quebec (Quebec) G3J 1X5 Canada	2. SECURITY CLASSIFICATION (Overall security classification of the document including special warning terms if applicable.) UNCLASSIFIED (NON-CONTROLLED GOODS) DMC A REVIEW: GCEC JUNE 2010

3. TITLE (The complete document title as indicated on the title page. Its classification should be indicated by the appropriate abbreviation (S, C or U) in parentheses after the title.)

RHA steel variations and their effects on ballistic protection

4. AUTHORS (last name, followed by initials – ranks, titles, etc. not to be used)

McIntosh, Grant W.J.

5. DATE OF PUBLICATION (Month and year of publication of document.) April 2012	6a. NO. OF PAGES (Total containing information, including Annexes, Appendices, etc.) 26	6b. NO. OF REFS (Total cited in document.) 1

7. DESCRIPTIVE NOTES (The category of the document, e.g. technical report, technical note or memorandum. If appropriate, enter the type of report, e.g. interim, progress, summary, annual or final. Give the inclusive dates when a specific reporting period is covered.)

Technical Memorandum

8. SPONSORING ACTIVITY (The name of the department project office or laboratory sponsoring the research and development – include address.)

Defence R&D Canada – Valcartier
2459 Pie-XI Blvd North
Quebec (Quebec)
G3J 1X5 Canada

9a. PROJECT OR GRANT NO. (If appropriate, the applicable research and development project or grant number under which the document was written. Please specify whether project or grant.)	9b. CONTRACT NO. (If appropriate, the applicable number under which the document was written.)
10a. ORIGINATOR'S DOCUMENT NUMBER (The official document number by which the document is identified by the originating activity. This number must be unique to this document.) DRDC Valcartier TM 2011-533	10b. OTHER DOCUMENT NO(s). (Any other numbers which may be assigned this document either by the originator or by the sponsor.)

11. DOCUMENT AVAILABILITY (Any limitations on further dissemination of the document, other than those imposed by security classification.)

Unlimited

12. DOCUMENT ANNOUNCEMENT (Any limitation to the bibliographic announcement of this document. This will normally correspond to the Document Availability (11). However, where further distribution (beyond the audience specified in (11) is possible, a wider announcement audience may be selected.))

Unlimited

13. ABSTRACT (A brief and factual summary of the document. It may also appear elsewhere in the body of the document itself. It is highly desirable that the abstract of classified documents be unclassified. Each paragraph of the abstract shall begin with an indication of the security classification of the information in the paragraph (unless the document itself is unclassified) represented as (S), (C), (R), or (U). It is not necessary to include here abstracts in both official languages unless the text is bilingual.)

A short study was undertaken to see if the ballistic performance of ¼" RHA steel plates can vary from batch-to-batch. Several random samples from the DRDC Valcartier stock were tested in a V50 test using a 5.56-mm Bofors armour piercing round. Small but statistically significant variations in the V50 were found even though all the samples were within the accepted standards for RHA.

14. KEYWORDS, DESCRIPTORS or IDENTIFIERS (Technically meaningful terms or short phrases that characterize a document and could be helpful in cataloguing the document. They should be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location may also be included. If possible keywords should be selected from a published thesaurus, e.g. Thesaurus of Engineering and Scientific Terms (TEST) and that thesaurus identified. If it is not possible to select indexing terms which are Unclassified, the classification of each should be indicated as with the title.)

armour piercing, RHA steel

Defence R&D Canada

Canada's Leader in Defence
and National Security
Science and Technology

R & D pour la défense Canada

Chef de file au Canada en matière
De science et de technologie pour
la défense et la sécurité nationale

DEFENCE R&D DÉFENSE

www.drdc-rddc.gc.ca