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# WATERTOWN ARSENAL LABORATORY

# **MEMORANDUM REPORT**

NO. WAL 710/692

DTIC

Resistance of Monel Metal and Two High-Nickel Alloys of Various Hardnesses to Perforation by Flak-Simulating Projectiles

BY

J. F. Sullivan  
Asst. Engineer

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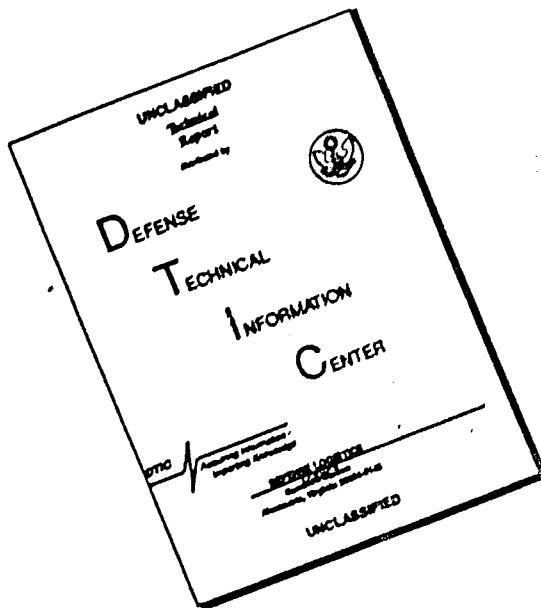
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DATE 11 September 1944

**WATERTOWN ARSENAL  
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WATERTOWN ARSENAL LABORATORYMemorandum Report No. WAL 710/692

20th Partial Report on Problem B-8.2

A-1

11 September 1944

Resistance of Monel Metal and Two High-Nickel Alloys of Various Hardnesses to Perforation by Flak-Simulating Projectiles

1. In accordance with a request from the Office, Chief of Ordnance<sup>1</sup>, tests have recently been conducted at this arsenal on one type of Monel Metal and two types of high-nickel alloys in various conditions of hardness as supplied by the International Nickel Company.

2. The resistance of none of these samples to perforation by cal. .45 steel-jacketed ball projectiles or by cal. .22 fragment simulating projectiles, G-22, was comparable with that of an equivalent weight of Hadfield manganese steel. In general, the resistance of the softer specimens of a given alloy whose hardnesses had been developed by the same process tended to be superior to that of the harder specimens of the same type. At a given hardness, however, specimens whose hardness had been developed by cold working plus age hardening were greatly superior to those whose hardness had been achieved as a result of cold working alone. Of the three alloys tested, the modified "Z" nickel in its best condition was superior to the others. In its other conditions, however, its resistance was not substantially different from that of any other alloy in similar conditions.

3. The resistance characteristics of three non-ferrous alloys high in nickel content were investigated. Samples of each alloy were developed to different stages of hardness by each of the following methods:

- a. Annealed.
- b. Annealed and age hardened.
- c. Cold rolled 1/4 hard.
- d. Cold rolled 1/4 hard and age hardened.
- e. Cold rolled 1/2 hard.
- f. Cold rolled 1/2 hard and age hardened.
- g. Cold rolled full hard.
- h. Cold rolled full hard and age hardened.

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O.O. 400.112/9531 - Wm 400.112/3616.

Report No. WAL 762/253(c)

4. Hardness and actual thickness determinations were made on all 144 samples received. A random sample of each alloy in each condition of hardness was selected and, by weighing and measuring, the thickness of steel of equivalent weight was determined. Two samples of each alloy in each condition were selected for ballistic testing with the cal. .45 steel-jacketed ball projectile and two additional samples for testing with the 17 grain cal. .22 fragment-simulator, G-2. These plates were rigidly mounted on wooden ballistic frames allowing an 8" x 8" area to remain unsupported from the rear into which area impacts of the test projectiles were directed. The results of all these tests appear in Table I, and the effect of hardness on the resistance of these materials to perforation is illustrated in Figures 1 to 3.

5. A determination of the physical properties of representative samples of each alloy in each condition was made in the laboratories of the International Nickel Company at Huntington, West Virginia. These results appear as Table II. In an earlier report it had been contended that a material best combining ductility and tensile strength should afford best resistance to fragment perforation. It is encouraging to note that the modified 2 Nickel in the annealed plus age hardened condition which has most successfully combined these apparently incompatible properties also has afforded highest resistance to perforation by the cal. .45 ball projectile.

6. The general inferiority of these alloys, even in their most resistant condition, to Hadfield manganese steel of equivalent weight would seem to discourage further consideration of them as potential body armor components.

*J. F. Sullivan*

J. F. Sullivan  
Asst. Engineer

APPROVED:

*N. A. Matthews*

N. A. MATTHEWS  
Major, Ord. Dept.  
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3. WAL Report No. 710/636.

TABLE I

Summary of Results of Tests for Resistance to Perforation  
Conducted at Watertown Arsenal on Samples of Various Alloys of  
Nickel in Various Conditions of Hardness

Sample No.	Alloy	Condition	Hardness Equivalent		Act. Gauge	Equiv. Steel Gauge	Ballistic Limit
			Rockwell	BHN			
AK-1	X Monel	Annealed	69 Rb	121	.043"	--	593
AK-2	"	"	68 Rb	120	.043"	--	672
AK-3	"	"	70 Rb	123	.044"	--	1223
AK-4	"	"	69 Rb	121	.044"	--	1245
AK-5	"	"	69 Rb	121	.044"	--	—
AK-6	"	"	69 Rb	121	.044"	.050"	—
BK-1	X Monel	Annealed and age hardened	28 Rc	277	.046"	--	633
BK-2	"	"	29 Rc	285	.046"	--	626
BK-3	"	"	29 Rb	285	.045"	--	1208
BK-4	"	"	28 Rc	277	.045"	.050"	1260
BK-5	"	"	28 Rc	277	.044"	--	—
BK-6	"	"	28 Rc	277	.045"	--	—
CK-1	X Monel	Cold rolled & hard	93 Rb	201	.043"	--	436
CK-2	"	"	93 Rb	201	.042"	--	492
CK-3	"	"	93 Rb	201	.044"	.049"	—
CK-4	"	"	93 Rb	201	.044"	--	1110
CK-5	"	"	93 Rb	201	.044"	--	1130
CK-6	"	"	93 Rb	201	.044"	--	—

1Cal. .45 steel-jacketed ball projectile - 230 grains.

2Cal. .22 flak-simulating projectile, G-2 - 17 grains.

TABLE I (CONT'D.)

Sample No.	Alloy	Condition	Hardness		Act. Gauge	Equiv. Steel Gauge	Ballistic Limit Cal. 451 G-22
			Rockwell	Equivalent BHN			
ML-1	X Monel	Cold rolled & hard and age hardened	34 Rc	330	.044"	---	650
ML-2	"	"	34 Rb	330	.045"	---	527
ML-3	"	"	34 Rb	330	.044"	-.019"	1152
ML-4	"	"	34 Rc	330	.044"	-.019"	1125
ML-5	"	"	35 Rc	339	.045"	---	---
ML-6	"	"	34 Rb	330	.044"	---	---
ML-1	X Monel	Cold rolled & hard	98 Rb	229	.043"	---	494
ML-2	"	"	98 Rb	229	.042"	---	462
ML-3	"	"	99 Rb	240	.043"	---	968
ML-4	"	"	100 Rb	250	.043"	.048"	975
ML-5	"	"	100 Rb	250	.043"	---	---
ML-6	"	"	99 Rb	240	.043"	---	---
ML-1	X Monel	Cold rolled & hard and age hardened	34 Rc	330	.044"	---	529
ML-2	"	"	35 Rc	339	.045"	---	558
ML-3	"	"	36 Rc	349	.045"	---	1043
ML-4	"	"	35 Rc	339	.044"	.019"	1093
ML-5	"	"	35 Rc	339	.043"	---	---
ML-6	"	"	35 Rb	339	.043"	---	---
CL-1	X Monel	Cold rolled full hard	102 Rb	264	.043"	---	455
CL-2	"	"	103 Rb	274	.043"	---	444
CL-3	"	"	103 Rb	274	.043"	---	900
CL-4	"	"	102 Rb	264	.043"	---	938
CL-5	"	"	102 Rb	264	.043"	.048"	---
CL-6	"	"	102 Rb	264	.043"	---	---

TABLE I (CONT'D)

Sample No.	Alloy	Condition	Hardness Equivalent		Act. Gauge	Equiv. Steel Gauge	Ballistic Limit	
			Rockwell	BHN			Cal. 451	G-22
HK-1	K Monel	Cold rolled full hard and age hardened	40 Rc	386	.045"	--	549	--
HK-2	"	"	39 Rc	379	.045"	--	467	--
HK-3	"	"	41 Rc	396	.043"	.049"	1062	1000
HK-4	"	"	39 Rc	379	.044"	--	--	--
HK-5	"	"	39 Rc	379	.044"	--	--	--
HK-6	"	"	40 Rc	386	.043"	--	--	--
AZ-1	Z Nickel	Annealed	77 Rb	139	.044"	--	635	--
AZ-2	"	"	77 Rb	139	.044"	--	653	--
AZ-3	"	"	78 Rb	141	.044"	--	--	1280
AZ-4	"	"	78 Rb	141	.044"	--	--	1275
AZ-5	"	"	78 Rb	141	.044"	.049"	--	--
AZ-6	"	"	78 Rb	141	.043"	--	--	--
BZ-1	Z Nickel	Annealed and age hardened	34 Rc	330	.043"	--	<397	--
BZ-2	"	"	34 Rc	330	.043"	--	362	--
BZ-3	"	"	34 Rc	330	.044"	--	--	890
BZ-4	"	"	34 Rc	330	.044"	--	--	802
BZ-5	"	"	35 Rc	339	.043"	.049"	--	--
BZ-6	"	"	35 Rc	339	.044"	--	--	--
CZ-1	Z Nickel	Cold rolled & hard	20 Rc	225	.043"	--	477	--
CZ-2	"	"	20 Rc	225	.043"	--	457	--
CZ-3	"	"	20 Rc	225	.043"	--	--	1109
CZ-4	"	"	20 Rc	225	.043"	--	--	1118
CZ-5	"	"	19 Rc	220	.043"	.049"	--	--
CZ-6	"	"	19 Rc	220	.042"	--	--	--

TABLE I (CONT'D)

Sample No.	Alloy	Condition	Hardness Equivalent		Act. Gauge	Equiv. Steel Gauge	Ballistic Limit	
			Rockwell	BHN			Cal., 451	G-22
DZ-1	Z Nickel	Cold rolled & hard and age hardened	38 Rc	367	.043"	--	<340	--
DZ-2	"	"	39 Rc	379	.043"	--	359	--
DZ-3	"	"	39 Rc	379	.043"	--	875	862
DZ-4	"	"	38 Rc	367	.042"	--	--	--
DZ-5	"	"	38 Rc	367	.042"	--	--	--
DZ-6	"	"	38 Rc	367	.042"	.048"	--	--
EZ-1	Z Nickel	Cold rolled & hard	27 Rc	269	.044"	--	460	--
EZ-2	"	"	27 Rc	269	.045"	--	450	--
EZ-3	"	"	27 Rc	269	.044"	--	--	998
EZ-4	"	"	28 Rc	277	.045"	--	--	1037
EZ-5	"	"	27 Rc	269	.043"	--	--	--
EZ-6	"	"	27 Rc	269	.042"	.048"	--	--
FZ-1	Z Nickel	Cold rolled & hard and age hardened	36 Rc	349	.043"	--	413	--
FZ-2	"	"	35 Rc	339	.043"	--	480	--
FZ-3	"	"	35 Rc	339	.043"	--	--	872
FZ-4	"	"	36 Rc	349	.044"	.044"	--	933
FZ-5	"	"	34 Rc	330	.043"	.048"	--	--
FZ-6	"	"	35 Rc	339	.043"	--	--	--
GZ-1	Z Nickel	Cold rolled full hard	34 Rc	330	.044"	--	422	--
GZ-2	"	"	35 Rc	339	.043"	--	372	--
GZ-3	"	"	34 Rc	330	.044"	--	--	905
GZ-4	"	"	34 Rc	330	.045"	--	--	888
GZ-5	"	"	34 Rc	330	.043"	.049"	--	--
GZ-6	"	"	35 Rc	339	.044"	.049"	--	--

TABLE I (CONT'D)

Sample No.	Alloy	Condition	Hardness		Act. Gauge	Equiv. Steel Gauge	Ballistic Limit	
			Rockwell	Equivalent BHN			Cal. 451	G-22
HZ-1	Z Nickel	Cold rolled full hard and age hardened	41 Rc	396	.043"	--	380	--
HZ-2	"	"	41 Rc	396	.044"	--	397	--
HZ-3	"	"	41 Rc	396	.043"	--	878	--
HZ-4	"	"	42 Rc	406	.044"	--	--	1005
HZ-5	"	"	41 Rc	396	.044"	--	--	--
HZ-6	"	"	41 Rc	396	.044"	.050"	--	--
AZM-1	Mod. Z Nickel	Annealed "	82 Rb	153	.045"	--	648	--
AZM-2	"	"	81 Rb	150	.044"	--	783	--
AZM-3	"	"	81 Rb	150	.043"	--	1373	--
AZM-4	"	"	78 Rb	141	.044"	--	--	1530
AZM-5	"	"	80 Rb	147	.045"	.048"	--	--
AZM-6	"	"	82 Rb	153	.045"	--	--	--
B2M-1	Mod. Z Nickel	Annealed and age hardened "	35 Rc	339	.045"	--	758	--
B2M-2	"	"	35 Rc	339	.044"	--	784	--
B2M-3	"	"	36 Rc	349	.043"	--	--	1326
B2M-4	"	"	35 Rc	339	.042"	--	--	1273
B2M-5	"	"	36 Rc	349	.044"	.046"	--	--
B2M-6	"	"	36 Rc	349	.043"	--	--	--
C2M-1	Mod. Z Nickel	Cold rolled & hard "	22 Rc	238	.043"	--	650	--
C2M-2	"	"	21 Rc	232	.044"	--	602	--
C2M-3	"	"	21 Rc	232	.045"	--	--	1252
C2M-4	"	"	20 Rc	226	.043"	--	--	1325
C2M-5	"	"	22 Rc	238	.043"	.046"	--	--
C2M-6	"	"	26 Rc	262	.044"	--	--	--
D2M-1	Mod. Z Nickel	Cold rolled & hard and age hardened "	38 Rc	367	.042"	--	592	--
D2M-2	"	"	39 Rc	379	.042"	--	668	--
D2M-3	"	"	39 Rc	379	.044"	--	--	1345
D2M-4	"	"	39 Rc	379	.051"	--	--	1700
D2M-5	"	"	39 Rc	379	.042"	--	--	1281
D2M-6	"	"	39 Rc	379	.043"	.046"	--	--

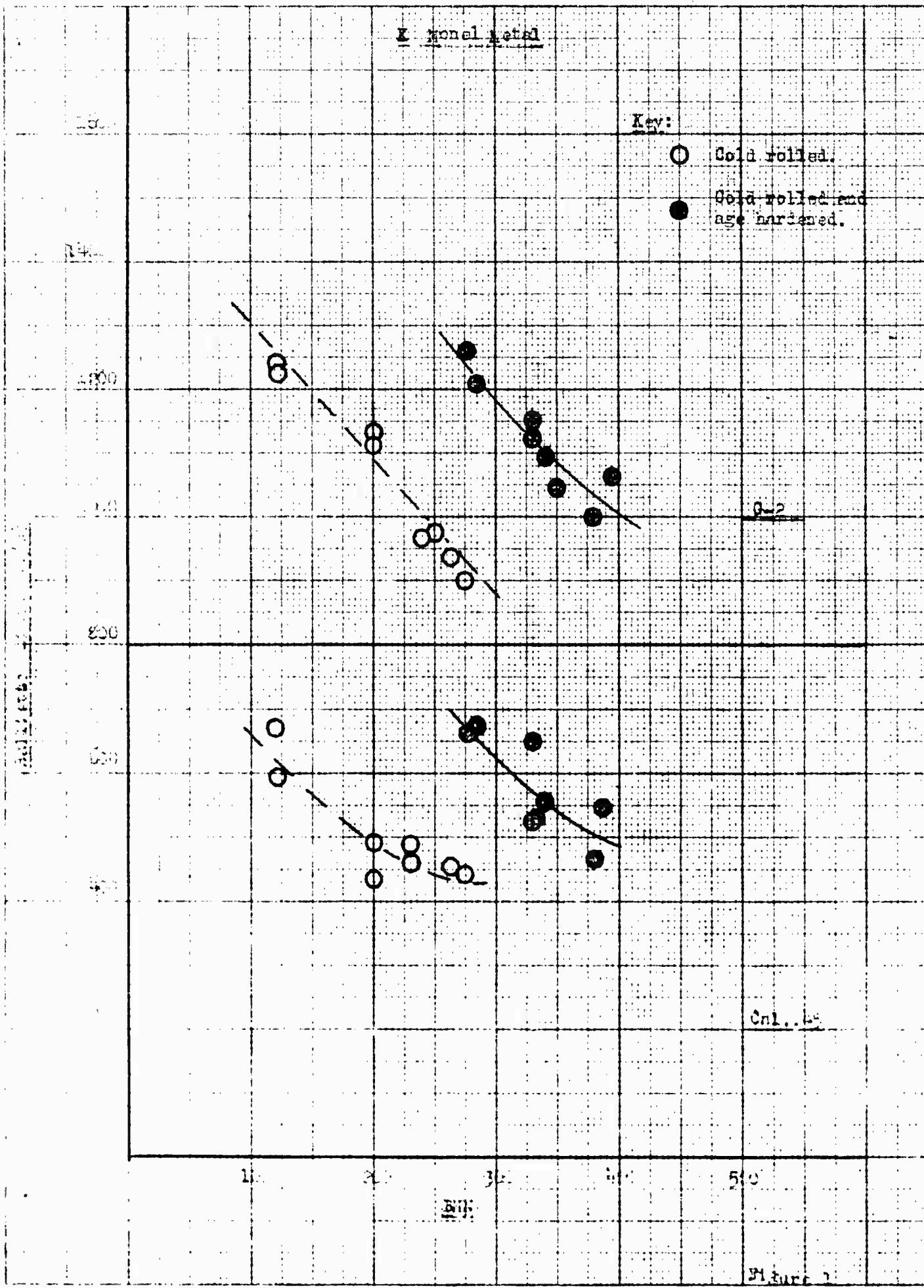
TABLE I (CONT'D)

Sample No.	Alloy	Condition	Hardness		Act. Gauge	Equiv. Steel Gauge	Ballistic Limit	
			Rockwell	Equivalent BHN			Cal. 451	C-22
EZM-1	Mod. Z	Cold rolled & hard	27 RC	269	.044"	--	554	--
EZM-2	Nickel	"	28 RC	277	.043"	--	549	--
EZM-3	"	"	31 RC	302	.044"	--	1238	--
EZM-4	"	"	31 RC	302	.044"	--	1167	--
EZM-5	"	"	32 RC	311	.044"	--	--	--
EZM-6	"	"	29 RC	285	.043"	.047"	--	--
FZM-1	Mod. Z	Cold rolled & hard and age hardened	42 RC	406	.044"	--	636	--
FZM-2	Nickel	"	41 RC	396	.044"	--	643	--
FZM-3	"	"	41 RC	396	.043"	--	1232	--
FZM-4	"	"	42 RC	406	.043"	--	1250	--
FZM-5	"	"	41 RC	396	.044"	--	--	--
FZM-6	"	"	42 RC	406	.043"	.048"	--	--
GZM-1	Mod. Z	Cold rolled full hard	36 RC	349	.044"	--	457	--
GZM-2	Nickel	"	36 RC	349	.045"	--	434	--
GZM-3	"	"	37 RC	358	.044"	--	1060	--
GZM-4	"	"	37 RC	358	.045"	--	1037	--
GZM-5	"	"	36 RC	349	.044"	--	--	--
GZM-6	"	"	37 RC	358	.045"	.047"	--	--
HZM-1	Mod. Z	Cold rolled full hard and age hardened	45 RC	435	.044"	--	610	--
HZM-2	Nickel	"	45 RC	435	.045"	--	581	--
HZM-3	"	"	45 RC	435	.043"	--	1188	--
HZM-4	"	"	45 RC	435	.044"	--	1236	--
HZM-5	"	"	45 RC	435	.045"	--	--	--
HZM-6	"	"	44 RC	425	.045"	.048"	--	--

TABLE II.

Summary of Physical Tests Conducted at Huntington, W. Va.  
Laboratory of International Nickel Company

Alloy	Condition	Yield Strength P. S. I.		Tensile Strength P. S. I.	Elongation %
		Mod.	2		
X	Annealed	37,600		100,000	38
X	Annealed and Age Hardened	105,000		169,000	18
X	Cold Rolled & Hard	93,800		116,000	20
X	Cold Rolled & Hard and Age Hardened	132,000		181,000	14
X	Cold Rolled & Hard	121,000		129,000	5
X	Cold Rolled & Hard and Age Hardened	139,000		184,000	11
X	Cold Rolled Full Hard	136,000		147,000	4
X	Cold Rolled Full Hard and Age Hardened	143,000		195,000	9
2	Annealed	44,300		103,600	35
2	Annealed and Age Hardened	128,000		158,000	10
2	Cold Rolled & Hard	97,800		120,700	24
2	Cold Rolled & Hard and Age Hardened	146,000		172,000	8
2	Cold Rolled & Hard	130,500		148,000	6
2	Cold Rolled & Hard and Age Hardened	154,000		175,000	8
2	Cold Rolled Full Hard	163,700		180,000	3
2	Cold Rolled Full Hard and Age Hardened	170,000		194,000	3
Mod. 2	Annealed	56,500		114,000	48
Mod. 2	Annealed and Age Hardened	112,400		170,600	25
Mod. 2	Cold Rolled & Hard	107,800		131,000	23
Mod. 2	Cold Rolled & Hard and Age Hardened	139,200		187,700	14
Mod. 2	Cold Rolled & Hard	124,700		154,600	12.5
Mod. 2	Cold Rolled & Hard and Age Hardened	153,400		196,100	11.5
Mod. 2	Cold Rolled Full Hard	161,400		193,700	3
Mod. 2	Cold Rolled Full Hard and Age Hardened	200,000		230,700	8



## 2 Nickel

Rev:

○ Cold rolled.  
● Cold rolled and  
age hardened.

1600

1400

1200

1000

800

600

400

200

Ballistic limit (ft/lb)

100

200

300

mm

400

500

Figure 2

G-2

Cal. 45

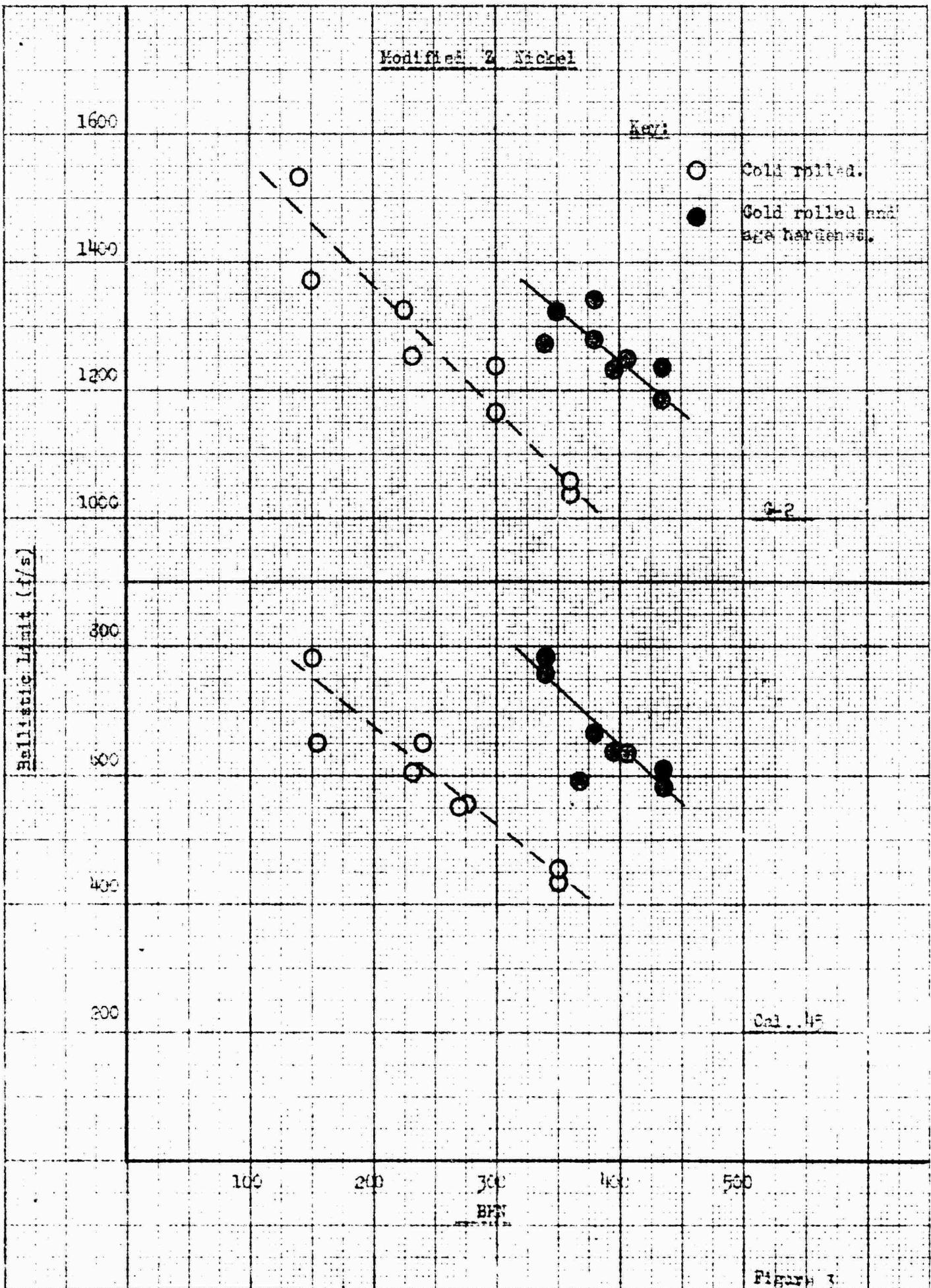


Figure 3