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PROGRESS REPORT

March 18, 1942

to

WATERTOWN ARSENAL,
UNITED STATES ARMY

on

Research Investigation of
Armor Plate Steels

S-547

BATTELLE
MEMORIAL INSTITUTE
505 King Avenue
COLUMBUS, OHIO

FORM 49

(1)

#3

PROGRESS REPORT

on

RESEARCH INVESTIGATION OF ARMOR PLATE STEELS

to

WATERTOWN ARSENAL, UNITED STATES ARMY

by

M. L. Samuels and C. H. Lorig

BATTELLE MEMORIAL INSTITUTE

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SUMMARY

The present report is primarily for the purpose of showing the results of ballistic tests and subsequent cross-section hardness surveys on the last group of twenty-seven heats. Data concerning the making and heat treating of this set of plates were included in the February 6, 1942, report.

The compositions included in this group of steels were given in a previous report but they are listed again for reference in Table 13.

Ballistic tests were made at Watertown Arsenal and the plates were subsequently returned to Battelle for cross-section hardness surveys. Complete results of the hardness surveys are shown in Table 14. With the exception of two heats, No. 7688 and No. 7689, which are low manganese, plain carbon steels, the actual hardness values obtained at points in the plate near which ballistic limits were determined fall fairly close to the respective ranges intended. Hardness values and ballistic limits for the

entire group of eighty-one plates are given in Table 15. Photographs showing the nature of the fractures resulting from bullet penetration are given as Figures 147A to 227, inclusive.

Table 15 shows that, with the exception of the two low manganese, plain carbon heats, all of the steels passed the acceptance limit of 2100 feet per second even at the 310-330 Brinell range. The lowest ballistic limit obtained, excepting the two heats listed above, was 2119 feet per second, and the highest was 2246 feet per second for the 310-330 Brinell hardness range. No steel failed to pass the acceptance limit at either of the two higher hardness ranges. Three back spalls were reported at the 310-330 Brinell range, two at the 350-370 range, and seven at the 400-420 Brinell range.

Ballistic limit values were plotted against hardness for each of the twenty-seven heats. The resulting curves are shown as Figures 228 to 254, inclusive. With very few exceptions these curves for the individual heats show a marked trend toward higher ballistic limits with increasing hardness. A composite graph including test results from 129 plates, representing the original list of forty-three compositions, is given as Figure 255.

For the purpose of facilitating comparisons, Table 16 was made up. This table includes the forty-three heats on which full data are available, and they are arranged in a descending order according to the ballistic limit at each of the three hardness levels. An additional column showing average ballistic limits for the three hardness levels is also included.

EXPERIMENTAL WORK

Ballistic Test Results

Ballistic tests were made at Watertown on the plates from a group of twenty-seven heats during the period from February 13 to February 17. Compositions included in this group of heats have been given in a previous report, but for the purpose of reference, they are again shown in Table 13.

TABLE 13. CHEMICAL COMPOSITION OF LAST GROUP OF TWENTY-SEVEN STEELS

Heat No.	Chemical Composition, Per Cent								
	C	Mn	Si	Ni	Cr	Mo	V	Cu	Ti
7688	.33	.43	.24						
7689	.33	.81	.26						
7690	.32	1.24	.28						
7691	.31	1.73	.29						
7692	.31	.75	.26	2.01					
7693	.30	.70	.25	3.55					
7694	.31	.73	.27	5.13					
7695	.30	1.24	.24	2.01					
7696	.31	.81	.27	1.3/1.6	.83				
7697	.28	.79	.24	3.6/3.9	2.61				
7702	.31	.82	.26	1.3/1.6	.70/.90	.25			
7703	.34	1.56	.46	3.3/3.7	.90/1.1	.34			
7712	.28	1.49	.26	1.3/1.6	.75/.90	.30			
7713	.32	.90	.25	1.3/1.6			.18		.16
7714	.31	1.46	.24						Grainal
7715	.32	1.42	.24						
7716	.31	1.44	.63		1.08		.18		Grainal
7717	.32	1.46	.69		1.07				
7718	.33	1.53	.27		.90/1.1	.40			
7719	.32	1.52	.27			.39			
7731	.34	.81	.30		1.53	.40			
7732	.31	.73	.21		1.32	.60/.80	.27		
7733	.31	1.51	.26					1.49	
7734	.35	1.52	.27			.40/.50		.45	
7735	.32	.84	.26					.42	
7736	.33	.88	.63	.50	.50	.30			
7737	.31	.77	.22	.50	.49	.30			

After the ballistic tests had been made the plates were sent back to Battelle for further examination. Photographs of the back surfaces, showing the extent of spalling around the bullet holes, are given in Figures 147A to 227, inclusive.

Cross-section hardness surveys were made at locations near the points where ballistic limits had been determined. Detail results from the hardness surveys are given in Table 14. The average Rockwell C hardness, expressed as equivalent Brinell, is shown with the corresponding ballistic limit in Table 15.

Relationship Between Hardness and Ballistic Limit

Curves were drawn by plotting ballistic limits against hardness values for each heat. The curves are constructed similarly to those made for the group of sixteen steels which were discussed in the last progress report. These curves are given in Figures 226 to 254, inclusive.

The general trend between hardness and ballistic limit has been shown by plotting values for all the forty-three compositions studied. See Figure 255. The identity of the individual heats is not given except in a few cases where the hardness values are considerably out of specifications. Specimens showing back spalls are designated by black circles in the graph.

Arrangement of Heats According to Ballistic Limits at Three Different Hardness Levels.

Table 16 shows the forty-three heats arranged in a descending order with respect to ballistic limits. A separate grouping is shown for each of the three different hardness levels and then a new listing is given in the right-hand column based upon average values from the three hardness levels.

TABLE 14. CROSS-SECTION HARDNESS SURVEYS FROM A GROUP OF TWENTY-SEVEN HEATS

Heat Number	Rockwell C Hardness Survey							Average Rc	Equivalent Brinell	Actual Brinell	
	1	2	3	4	5	6	7			Surface*	Center
7688-320	21	25	23	21	21	23	29	24	250	293	241
360	42	39	31	27	25	27	17	30	283	364	307
410	37	30	31	31	35	42	44	36	332	417	345
7689-320	35	34	33	32	33	34	35	34	313	320	306
360	38	37	35	34	35	37	38	36	332	363	337
410	43	43	41	40	41	42	43	42	393	415	395
7690-320	35	35	35	35	35	37	36	37	327	323	321
360	39	40	40	39	39	40	40	39.5	367	361	368
410	45	45	44	44	44	45	45	44.5	421	415	426
7691-320	35	35	36	35	35	35	34	35	322	323	323
360	39	40	41	41	40	40	40	40	372	363	373
410	44	45	45	44	43	45	44	44.5	421	415	417
7692-320	34	35	36	35	36	37	35	35	322	326	323
360	39	39	39	40	40	39	39	39	362	361	362
410	43	44	44	44	44	44	43	44	415	406	423
7693-320	36	36	35	36	36	36	35	35.5	327	328	331
360	39	40	39	40	40	40	40	40	372	365	370
410	44	45	44	44	44	43	42	43.5	409	405	415
7694-320	34	34	34	34	35	34	34	34	313	317	319
360	38	39	39	39	39	39	38	39	362	366	373
410	44	45	45	44	44	45	44	44.5	420	415	406
7695-320	34	35	35	35	35	35	35	35	322	319	321
360	38	39	39	40	40	40	39	39.5	366	366	370
410	44	44	44	44	45	44	44	44	413	415	426
7696-320	34	36	35	36	36	36	36	35.5	327	318	333
360	38	38	39	39	40	40	39	39	362	357	359
410	44	43	44	44	44	45	45	44	415	413	426
7697-320	34	36	36	36	37	36	35	36	332	322	321
360	40	40	40	40	40	41	40	40	372	357	368
410	44	45	45	45	45	45	46	45	426	418	420
7702-320	35	36	35	35	36	36	36	35.5	327	323	333
360	39	39	39	39	39	38	38	39	362	358	361
410	44	44	44	44	45	44	44	44	415	410	417
7703-320	34	34	34	34	34	35	35	34.5	317	323	307
360	39	39	39	39	39	39	39	39	362	357	363
410	43	44	44	44	44	45	45	44	415	413	415
7712-320	33	34	34	34	35	35	35	34.5	317	310	319
360	40	41	41	41	41	41	40	41	382	364	375
410	44	43	43	44	43	42	43	43	404	418	415

(Continued on page 96a.)

Heat Number	Rockwell C Hardness Survey 1	2	3	4	5	6	7	Average Rc	Equivalent Brinell	Actual Brinell Surface*	Center
7713-320	35	36	36	36	36	36	36	36	332	324	331
360	40	40	40	40	41	40	40	40	372	367	375
410	44	45	45	45	45	45	46	45	426	413	420
7714-320	34	35	34	34	34	34	35	34	313	310	313
360	38	37	37	37	37	37	37	37	342	354	345
410	44	44	43	44	44	44	44	44	415	415	417
7715-320	35	35	36	37	36	37	36	36	332	322	339
360	39	39	39	40	40	40	40	39.5	367	369	373
410	43	44	44	44	44	44	45	44	415	413	417
7716-320	35	35	35	36	35	35	35	35	322	322	321
360	40	41	41	40	41	40	41	40.5	377	364	375
410	44	44	44	44	44	43	44	44	415	409	415
7717-320	34	34	34	35	36	36	35	35	322	324	323
360	39	40	40	40	40	40	40	40	372	363	363
410	43	44	44	44	44	44	44	44	415	408	415
7718-320	34	35	35	34	35	34	34	34.5	318	318	320
360	39	39	37	38	39	39	39	38.5	357	356	361
410	43	44	44	44	44	44	44	44	415	408	415
7719-320	34	32	34	35	34	35	34	34	313	316	317
360	38	39	39	37	39	39	39	38.5	357	364	352
410	45	45	45	45	45	46	45	45	426	418	432
7731-320	33	33	34	34	34	35	34	34	313	336	315
360	41	42	41	41	42	42	41	41.5	385	369	385
410	44	44	45	44	44	44	45	44	415	412	423
7732-320	34	34	34	34	35	35	36	35.5	327	317	321
360	39	39	39	39	39	39	39	39	362	368	361
410	45	44	45	46	45	45	45	45	426	418	429
7733-320	35	35	35	36	35	35	34	35	322	323	321
360	40	40	39	40	40	40	40	40	372	368	361
410	42	42	43	43	43	43	43	43	404	418	398
7734-320	35	34	34	34	35	35	35	34.5	318	323	325
360	39	39	40	39	39	39	38	39	362	364	359
410	42	43	44	42	43	43	43	43	404	410	401
7735-320	36	36	35	35	36	36	36	36	332	324	321
360	39	40	40	40	40	40	39	40	372	363	363
410	43	44	43	43	43	43	43	43	404	401	398
7736-320	35	35	36	36	35	35	36	35.5	327	321	329
360	40	40	40	40	40	39	40	40	372	363	373
410	44	45	44	45	46	46	46	45	426	418	417
7737-320	35	35	35	36	35	36	36	35.5	327	325	329
360	40	39	39	40	40	40	40	40	372	363	373
410	41	44	44	43	43	43	44	43.5	409	409	412

* Surface Brinell reading after final heat treatment of plate.

TABLE 15. BRINELL HARDNESS AND BALLISTIC LIMITS OF 1/2"x6"x12" HOMOGENEOUS ARMOR PLATES - SERIES OF TWENTY-SEVEN STEELS

	410 Brinell				360 Brinell				320 Brinell			
Heat No.	Equiv. Brinell Hardness, Cross-Section	Ballistic Limit, f./s.	Shock	PTP	Equiv. Brinell Hardness, Cross-Section	Ballistic Limit, f./s.	Shock	PTP	Equiv. Brinell Hardness, Cross-Section	Ballistic Limit, f./s.	Shock	PTP
7688*	332	2127	O.K.	O.K.	283	2176	O.K.	O.K.	250	1923	B.S.	O.K.
7689	393	2358	O.K.	O.K.	332	2220	O.K.	O.K.	313	2068	O.K.	O.K.
7690	421	2259	B.S.	O.K.	367	2179	O.K.	O.K.	327	2170	O.K.	O.K.
7691	421	2301	O.K.	O.K.	372	2331	O.K.	O.K.	322	2161	O.K.	O.K.
7692	415	2330	B.S.	O.K.	362	2211	O.K.	O.K.	322	2162	O.K.	O.K.
7693	409	2319	O.K.	O.K.	372	2304	O.K.	O.K.	327	2194	O.K.	O.K.
7694	420	2299	O.K.	O.K.	362	2233	O.K.	O.K.	313	2171	O.K.	O.K.
7695	413	2242	O.K.	O.K.	366	2242	O.K.	O.K.	322	2147	O.K.	O.K.
7696	415	2372	O.K.	O.K.	362	2247	O.K.	O.K.	327	2141	O.K.	O.K.
7697	426	2413	B.S.	O.K.	372	2319	O.K.	B.S.	332	2124	O.K.	O.K.
7702	415	2337	O.K.	O.K.	362	2225	O.K.	O.K.	327	2186	O.K.	O.K.
7703	415	2420	B.S.	--	362	2256	O.K.	O.K.	317	2156	O.K.	O.K.
7712	404	2402	O.K.	O.K.	382	2304	O.K.	O.K.	317	2119	O.K.	O.K.
7713	426	2333	O.K.	--	372	2220	O.K.	O.K.	332	2148	O.K.	O.K.
7714	415	2322	Crack-B.S.	O.K.	342	2269	O.K.	O.K.	313	2178	O.K.	O.K.
7715	415	2335	O.K.	O.K.	367	2249	O.K.	O.K.	332	2176	O.K.	O.K.
7716	415	2363	B.S.	B.S.	377	2264	O.K.	O.K.	322	2206	O.K.	O.K.
7717	415	2389	O.K.	O.K.	372	2274	O.K.	O.K.	322	2246	B.S.	O.K.
7718	415	2314	O.K.	O.K.	357	2266	O.K.	O.K.	318	2186	O.K.	O.K.
7719	426	2377	B.S.	O.K.	357	2338	B.S.	O.K.	313	2171	O.K.	O.K.
7731	415	2373	O.K.	O.K.	385	2258	O.K.	O.K.	313	2144	O.K.	O.K.
7732	426	2380	O.K.	O.K.	362	2232	O.K.	O.K.	327	2136	O.K.	O.K.
7733	404	2287	Cracked in two.		372	2139	O.K.	O.K.	322	2144	B.S. E.H.	B.P.
7734	404	2389	O.K.	O.K.	362	2267	O.K.	O.K.	318	2188	O.K.	O.K.
7735	404	2366	O.K.	O.K.	372	2267	O.K.	O.K.	332	2159	O.K.	O.K.
7736	426	2371	O.K.	O.K.	372	2261	O.K.	O.K.	327	2134	O.K.	O.K.
7737	409	2378	O.K.	O.K.	372	2225	O.K.	O.K.	327	2235	O.K.	O.K.

* This steel was quenched in a 10% salt solution. The other steels were quenched in water, using the submerged spray head.

TABLE 16. ARRANGEMENT OF HEATS ACCORDING TO BALLISTIC LIMITS AT THREE

410 Brinell					360 Brinell						
Heat No.	Actual Hard.	Bal. Lt. F/S	Remarks		Heat No.	Actual Hard.	Bal. Lt. F/S	Remarks		Heat No.	Actual Hard.
7329	421	2455	Punching, 7/8"x3/16"	OK	7719	366	2338	Back spall threatening.	NG	7354	328
7111	404	2445	No spalls. Crack	NG	7691	372	2331	Full petalling	OK	7717	322
7355	417	2427	Back spall.	NG	7697	372	2319	Back spall.	NG	7737	327
7351	410	2426	Back spall.	NG	7693	372	2304	Back petal.	OK	7716	322
7703	415	2420	Back spall.	NG	7712	382	2304	Full petalling.	OK	7693	327
7354	404	2417	Full petalling.	OK	7354	358	2300	Radial crack.	?	7734	318
7697	426	2413	Back spall.	NG	7342	365	2289	Radial crack.	?	7702	327
7330	404	2412	Full petalling.	OK	7717	372	2274	Back petal.	OK	7718	318
7342	409	2410	Full petalling.	OK	7714	342	2269	Full petalling.	OK	7353	336
7712	404	2402	7/8"x15/16" exit diameter	OK	7734	362	2267	Back petal.	OK	7714	313
7717	415	2389	Back petal.	OK	7735	372	2267	Full petalling.	OK	7715	332
7734	404	2389	Back petal.	OK	7718	357	2266	Full petalling.	OK	7342	319
7340	418	2388	Face petal.	OK	7326	368	2264	Radial crack.	?-OK	7347	316
7732	426	2380	Back petal.	OK	7716	377	2264	Back petal.	OK	7719	313
7737	409	2378	Back petal.	OK	7736	372	2261	Full petalling.	OK	7694	313
7719	426	2377	Back spall.	NG	7111	363	2259	3/4"x3/4" exit diameter	OK	7690	327
7731	415	2373	Back petal.	OK	7731	385	2258	Full petalling.	OK	7692	322
7696	415	2372	Back petal.	OK	7703	362	2256	Full petalling.	OK	7691	322
7736	426	2371	3/4"x3/4" exit diameter	OK	7715	367	2249	3/4"x11/16" exit dia.	OK	7735	332
7735	404	2366	11/16"x5/8" exit dia.	OK	7696	362	2247	Full petalling.	OK	7111	312
7716	415	2363	Back spall.	NG	7350	375	2246	Back spall.	NG	7330	303
7327	412	2362	Back spall.	NG	7695	366	2242	Back petal.	OK	7703	317
7689	393	2358	25/32"x1/2" exit dia.	OK	7344	351	2235	Radial crack.	?	7355	307
7350	418	2356	Back spall.	NG	7694	362	2233	Back petal.	OK	7713	332
7348	402	2345	Back spall.	NG	7732	362	2232	3/4"x1/2" exit dia.	OK	7695	322
7702	415	2337	13/16"x9/16" exit dia.	OK	7702	362	2225	Full petalling.	OK	7733	322
7715	415	2335	27/32"x1/2" exit dia.	OK	7737	372	2225	Full petalling.	OK	7731	313
7713	426	2333	11/16"x11/16" exit dia.	OK	7689	332	2220	Full petalling.	OK	7696	327

NG TO BALLISTIC LIMITS AT THREE HARDNESS LEVELS

l emarks		320 Brinell Heat No.	Ac- tual Hard.	Bal. Lt. F/S	Remarks	Heat No.	Average Rating
ll threatening.	NG	7354	328	2247	.30 cal. satisfactory	OK 7354	2321
alling	OK	7717	322	2246	Back spall.	NG 7717	2303
ll.	NG	7737	327	2235	Back petal.	OK 7719	2295
al.	OK	7716	322	2206	Full petalling.	OK 7342	2292
talling.	OK	7693	327	2194	Full petalling.	OK 7111	2287
rack.	?	7734	318	2188	Full petalling.	OK 7697	2285
rack.	?	7702	327	2186	Full petalling.	OK 7734	2281
tal.	OK	7718	318	2186	Full petalling.	OK 7737	2279
talling.	OK	7353	336	2183	.30 cal. only.	OK 7716	2278
tal.	OK	7714	313	2178	Full petalling.	OK 7703	2277
talling.	OK	7715	332	2176	Full petalling.	OK 7712	2275
talling.	OK	7342	319	2176	.30 cal. only.	OK 7693	2272
crack.	?-OK	7347	316	2171	.30 cal. only.	OK 7755	2264
tal.	OK	7719	313	2171	Full petalling.	OK 7735	2264
talling.	OK	7694	313	2171	Full petalling.	OK 7691	2264
4" exit diameter	OK	7690	327	2170	Full petalling.	OK 7731	2258
talling.	OK	7692	322	2162	Full petalling.	OK 7330	2257
talling.	OK	7691	322	2161	Full petalling.	OK 7329	2257
1/16" exit dia.	OK	7735	332	2159	Full petalling.	OK 7714	2256
talling.	OK	7111	312	2157	.30 cal. only.	OK 7736	2255
pall.	NG	7330	303	2157	.30 cal. only.	OK 7718	2255
etal.	OK	7703	317	2156	Full petalling.	OK 7696	2253
crack.	?	7355	307	2150	.30 cal. only.	OK 7715	2253
etal.	OK	7713	332	2148	Full petalling.	OK 7702	2249
/2" exit dia.	OK	7695	322	2147	Full petalling.	OK 7732	2249
petalling.	OK	7733	322	2144	Incomplete back spall.	NG 7353	2247
petalling.	OK	7731	313	2144	Full petalling.	OK 7340	2244
petalling.	OK	7696	327	2141	Full petalling.	OK 7350	2242

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Table 16. Continued.

410 Brinell					360 Brinell							
Heat No.	Actual Hard.	Bal. Lt. F/S	Remarks		Heat No.	Actual Hard.	Bal. Lt. F/S	Remarks		Heat No.	Actual Hard.	
7692	415	2330	13/16"x12/16" exit dia.	OK	7713	372	2220	Full petalling.	OK	7732	327	2
7353	379	2328	Full petalling	OK	7340	363	2220	Radial crack.	?-OK	7736	327	2
7714	415	2322	Face spall, back spall.	NG	7353	349	2220	Complete penetration.	OK	7348	304	2
7693	409	2319	Back petal.	OK	7355	362	2215	Radial crack.	?-OK	7329	307	2
7718	415	2314	Back punching.	OK	7692	362	2211	Incomplete back spall.	NG	7697	332	2
7691	421	2301	Back petal.	OK	7327	370	2209	Radial crack.	?-OK	7326	339	2
7694	420	2299	3/4"x1/2" exit dia.	OK	7330	369	2203	Back spall.	NG	7340	321	2
7733	404	2287	Plate cracked.	NG	7329	366	2193	Radial crack.	?-OK	7350	333	2
7347	410	2274	Back spall.	NG	7341	355	2181	Radial crack.	?-OK	7344	302	2
7344	390	2267	Full petalling.	OK	7690	367	2179	Full petalling.	OK	7712	317	2
7690	421	2259	Back spall.	NG	7688	283	2176	7/8"x11/16" punching.	OK	7341	319	2
7326	420	2245	5/8"x7/8" exit dia.	OK	7348	369	2170	Radial crack.	?-OK	7327	305	2
7695	413	2242	3/4"x1/2" exit dia.	OK	7347	363	2150	Radial crack.	?-OK	7351	291	2
7341	413	2230	Punching blown out.	?	7733	372	2139	Back petal.	OK	7689	313	2
7688	332	2127	Back spall.	NG	7351	369	2135	Radial crack.	?-OK	7688	250	1

nell		320 Brinell						
emarks		Heat No.	Actual Hard.	Bal. Lt. F/S	Remarks		Heat No.	Average Rating
alling.	OK	7732	327	2136	9/16"xl/2" exit dia.	OK	7713	2234
rack.	?-OK	7736	327	2134	Full petalling	OK	7694	2234
penetration.	OK	7348	304	2132	.30 cal. only.	OK	7692	2234
rack.	?-OK	7329	307	2131	.30 cal. only.	OK	7327	2225
te back spall.	NG	7697	332	2124	Full petalling.	OK	7348	2219
rack.	?-OK	7326	339	2124	.30 cal. only.	OK	7351	2218
ll.	NG	7340	321	2123	.30 cal. only	OK	7639	2215
crack.	?-OK	7350	333	2123	.30 cal. only.	OK	7326	2211
crack.	?-OK	7344	302	2122	.30 cal. only.	OK	7695	2210
talling.	OK	7712	317	2119	Full petalling.	OK	7344	2208
/16" punching.	OK	7341	319	2108	.30 cal. only.	OK	7690	2203
crack.	?-OK	7327	305	2104	.30 cal. only.	OK	7347	2200
crack.	?-OK	7351	291	2094	Low ballistic value.	NG	7733	2190
tal.	OK	7689	313	2068	Low ballistic value.	NG	7341	2173
crack.	?-OK	7688	250	1923	Back spall. Low ballistic value	NG	7638	2075

2

DISCUSSION

In attempting to correlate ballistic test results with chemical composition, consideration of variations between duplicate plates from a given heat and between plates from duplicate heats should be taken into account. The variations might be attributed to several factors including, (a) accuracy of ballistic limit determinations, (b) small differences in composition within specification limits, as regards the major constituents, and (c) differences in minor constituents not ordinarily determined in chemical analysis. It is possible to make some comparisons between heats which have essentially the same compositions because a number of duplications were made in an effort to improve cleanliness ratings in some cases and to obtain larger melts in others.

The following groups of plates are similar within themselves in composition and are comparable as to hardness. The variations in ballistic limits may be construed as a result of the variables mentioned previously.

Heat No.	Chemical Composition, Per Cent								Limit F/S	Brinell Hardness
	C	Mn	Si	Ni	Cr	Mo	V	Cu		
7702	.31	.82	.26	1.3/1.6	.70/.90	.34			2225	362
7280	.35	.92	.28	1.3/1.6	.70/.90	.20/.30			2291	365
7101	.36	.85	.25	1.3/1.6	.70/.90	.20/.30			2328	388
7103	.36	1.53	.25	1.3/1.6	.75/.90	.25/.35			2319	375
7281	.36	1.63	.30	1.3/1.6	.75/.90	.25/.35			2275	369
7713	.32	.90	.25	1.3/1.6			.18		2220	372
7104	.33	.83	.2/.3	1.3/1.6			.10/.15		2318	375
7328 Mach.	.34	.85	.20		1.3/1.7	.35/.45			2237	363
7328 Roll.									2229	363
7343 Mach.	.45	.79	.19		1.10/1.30	.60/.80	.20/.30		2293	352
7343 Roll.									2312	363
7345 Mach.	.45	1.54	.28					1.4/1.6	2268	352
7345 Roll.									2287	352
7349 Mach.	.46	.71	.24			.40/.50		.30/.50	2260	352
7349 Roll.									2309	369
7352 Mach.	.44	1.11	1.03					1.3/1.6	2242	363
7352 Roll.									2285	341

When small variations in hardness between the plates of the groups listed above are taken into account, the results are seen to be fairly consistent with the exception of Heats 7713 and 7104. These two heats show a difference of 100 feet per second as regards ballistic limits even though the hardness values are practically identical. Since both the plates were sectioned for hardness surveys near the points at which ballistic limits were obtained, no errors in hardness determinations can be suspected.

A possible effect of carbon content on the ballistic limit can be traced in the same manner. The following list of heats includes those having essentially the same hardness and about the same analysis, except for carbon content.

Heat No.	Carbon, Per Cent	320 Group Ballistic Limit	320 Group Brinell Hardness	360 Group Ballistic Limit	360 Group Brinell Hardness	410 Group Ballistic Limit	410 Group Brinell Hardness
7690	.32			2179	367		
7276	.50			2136	357		
7691	.31					2301	421
7094	.48					2502	420
7693	.30			2304	372		
7096	.37			2357	375		
7694	.31			2233	362		
7097	.36			2388	375		
7695	.30			2242	366		
7098	.37			2350	380		
7696	.31	2141	327	2247	362		
7099	.37			2389	388		
7279	.40	2162	319	2149	341		
7714	.31					2322	415
7105	.48					2364	401
7715	.32					2335	415
7106	.48					2455	408
7716	.31			2264	377		
7107	.47			2339	375		

(Continued on page 101.)

Heat No.	Carbon, Per Cent	320 Group Ballistic Limit	320 Group Brinell Hardness	360 Group Ballistic Limit	360 Group Brinell Hardness	410 Group Ballistic Limit	410 Group Brinell Hardness
7717	.32					2389	415
7108	.50					2340	401
7718	.33			2266	357		
7109	.48			2324	375		
7719	.32			2338	357		
7110	.48			2334	388		
7732	.31			2232	362		
7343R	.45			2312	362		
7734	.35	2188	318	2267	362	2389	404
7348	.47	2132	304	2170	369	2345	402

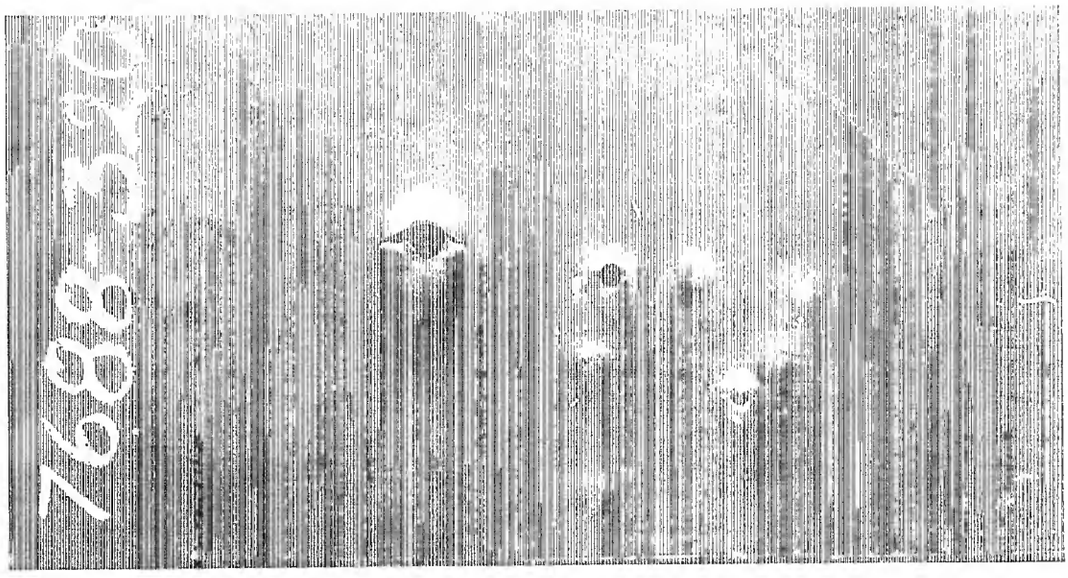
Thirteen of the cases in which comparisons are made show higher ballistic limits to be associated with the higher carbon content, but eight others show an opposite trend. Certainly no very marked decrease in ballistic limit values can be shown to follow the lowering of the carbon content to the .30/.35 per cent range.

FUTURE WORK

Plans for future work are to be discussed at the meeting in Watertown on March 12.

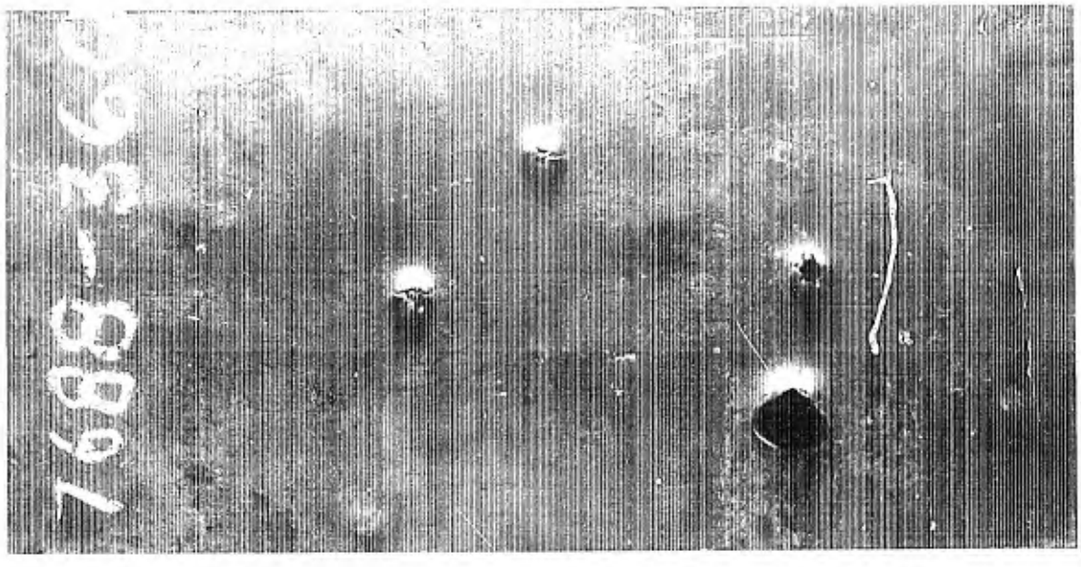
Data from which this report was written are recorded in Notebook No. 849, pages 47 to 99 inclusive, and Notebook No. 912, pages 4 to 11 inclusive.

MLS-CHL:DW
3/24/42



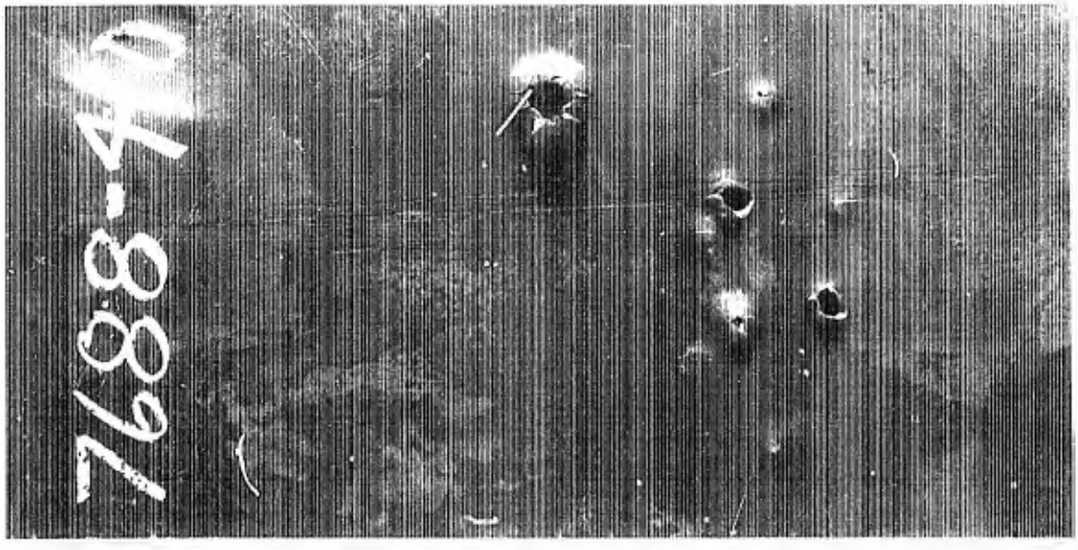
14667

Fig. 147A. Heat No. 7688-330. Back of plate - photographed 1/2 actual size. Cross-section equiv. Brinell hardness 250. Ballistic limit 1923 F/S.



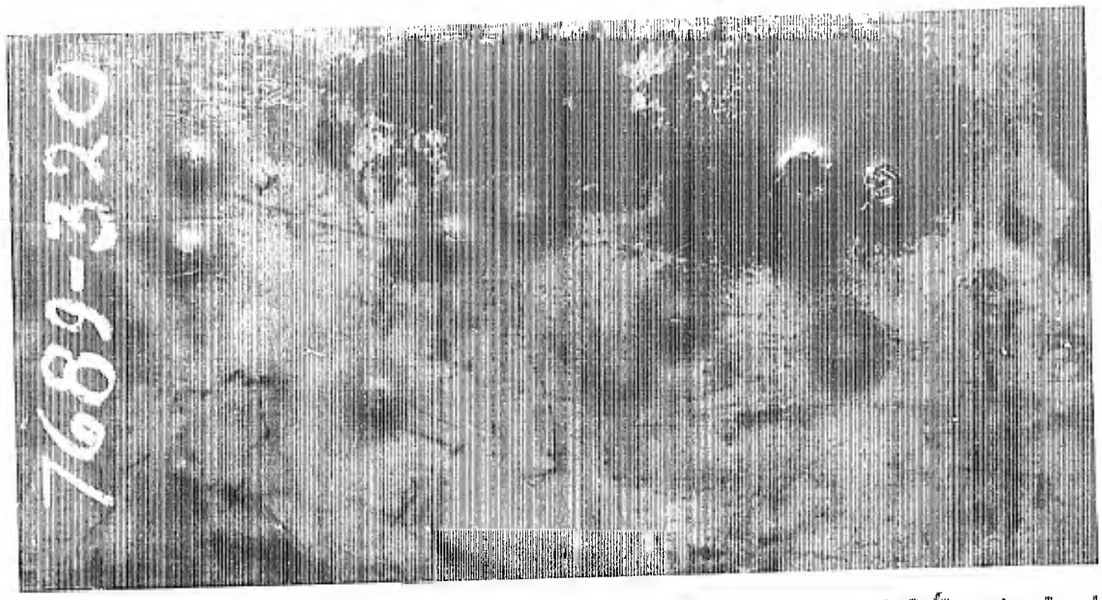
14669

Fig. 148. Same heat as shown above but at the 360 Brinell level. Cross-section equiv. Brinell hardness 283. Ballistic limit 2176 F/S



14686

Fig. 149. Same heat as shown above but at the 410 Brinell level. Cross-section equiv. Brinell hardness 432. Ballistic limit 3137 F/S.

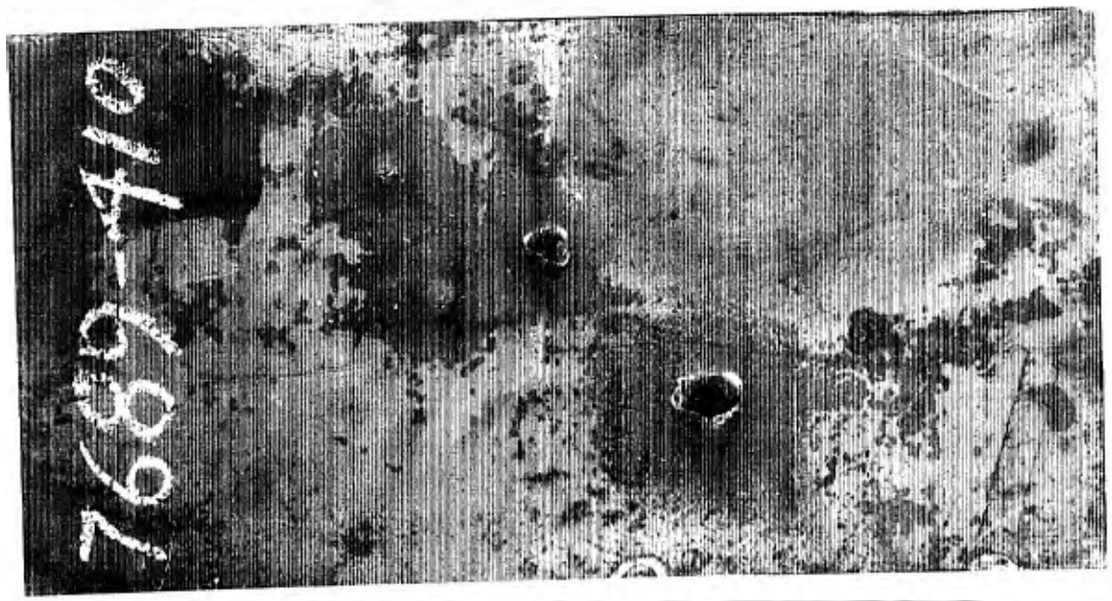


14558

Fig. 150. Heat No. 7689:320. Back of plate - photographed 1/2 actual size. Cross-section equiv. Brinell hardness 515. Ballistic limit 2068 F/S.

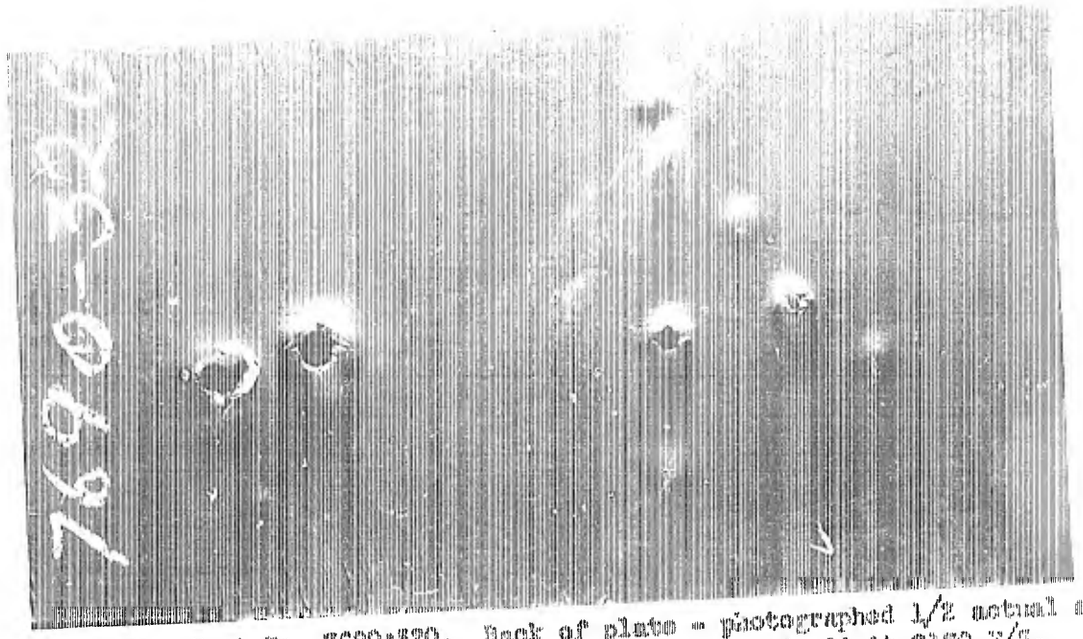
14559

Fig. 151. Same heat as shown above but at the 380 Brinell level. Cross-section equiv. Brinell hardness 382. Ballistic limit 2220 F/S.



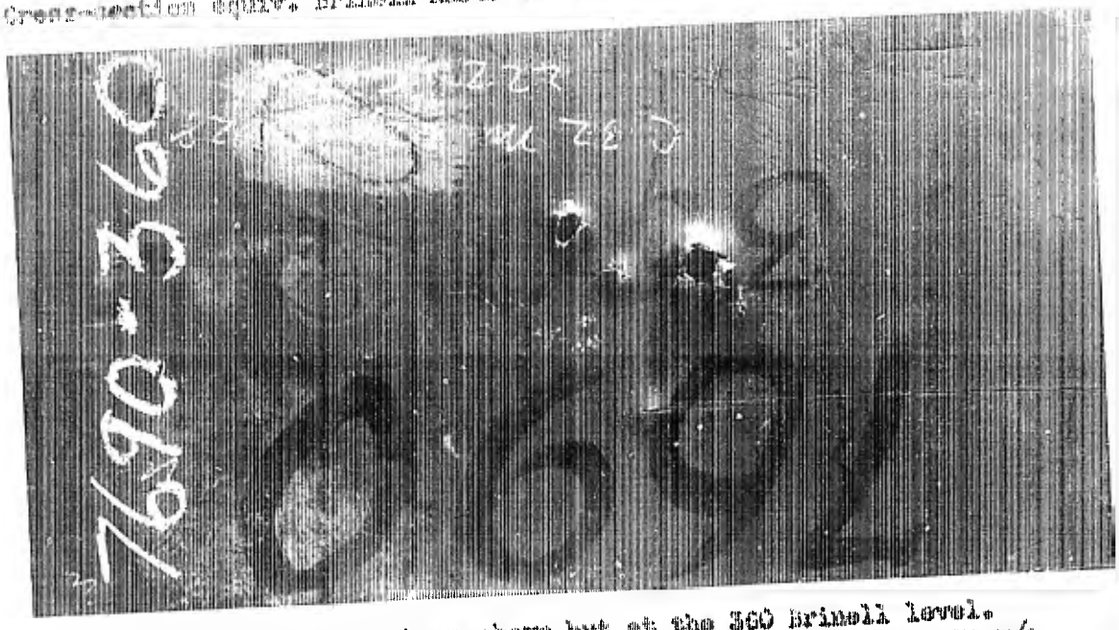
14560

Fig. 152. Same heat as shown above but at the 410 Brinell level. Cross-section equiv. Brinell hardness 395. Ballistic limit 2368 F/S.



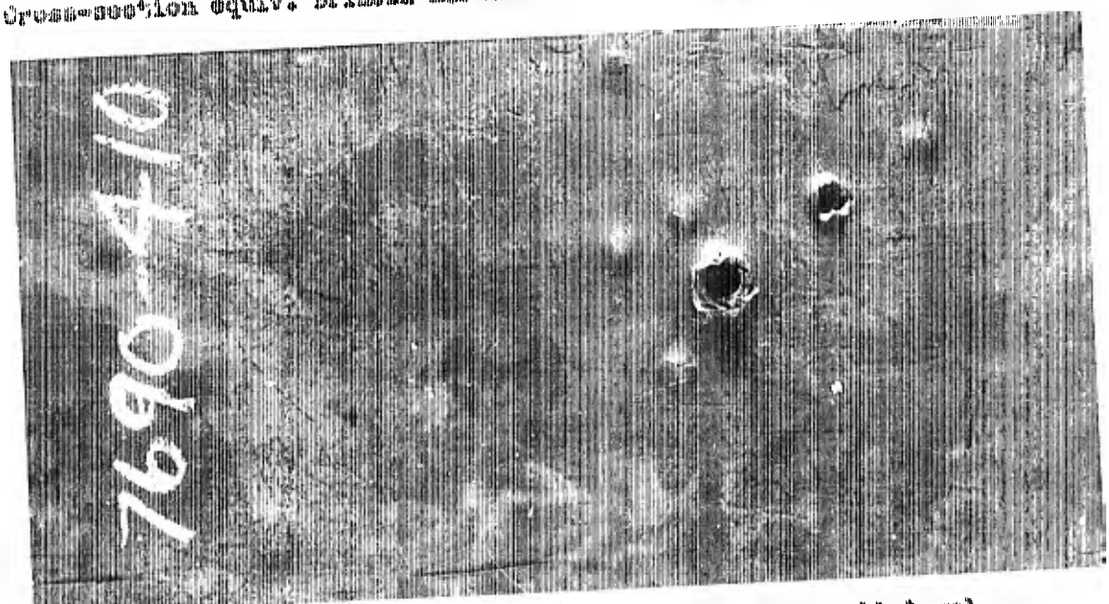
14547

Fig. 163. Heat No. 7690t320. Back of plate - photographed 1/2 actual size. Cross-section equiv. Brinell hardness 327. Ballistic limit 2170 f/s.



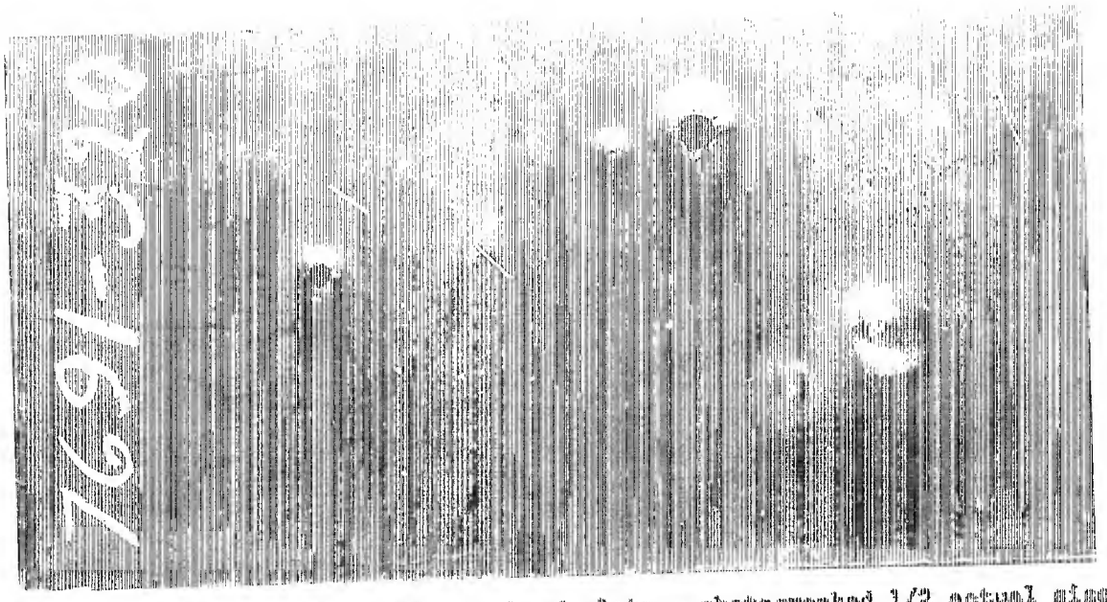
14676

Fig. 164. Same heat as shown above but at the 360 Brinell level. Cross-section equiv. Brinell hardness 367. Ballistic limit 2175 f/s.



14597

Fig. 165. Same heat as shown above but at the 410 Brinell level. Cross-section equiv. Brinell hardness 401. Ballistic limit 2250 f/s.



14559

Fig. 166. Heat No. 7691320. Back of plate - photographed 1/2 actual size. Cross-section equiv. Brinell hardness 322. Ballistic limit 2161 F/S.

14565

Fig. 167. Same heat as shown above but at the 360 Brinell level. Cross-section equiv. Brinell hardness 372. Ballistic limit 2351 F/S.

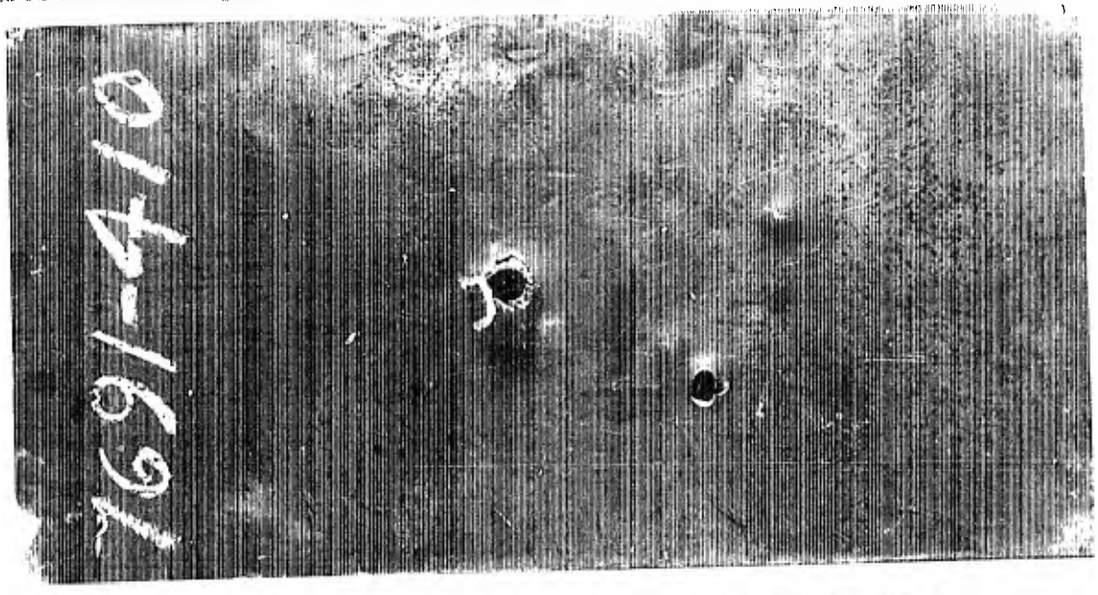


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Fig. 168. Same heat as shown above but at the 410 Brinell level. Cross-section equiv. Brinell hardness 421. Ballistic limit 2301 F/S.

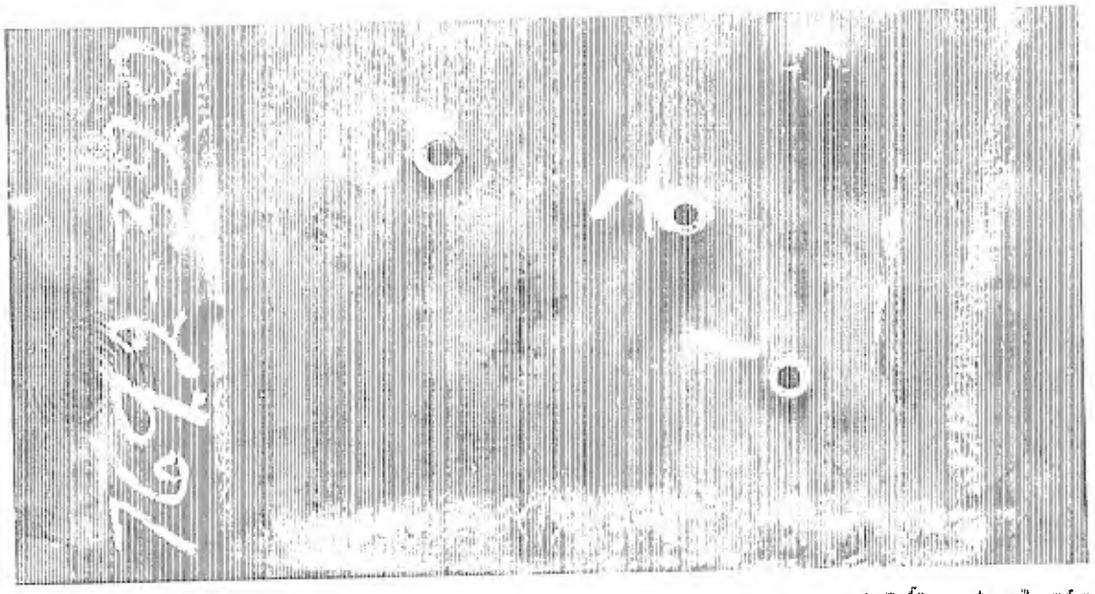

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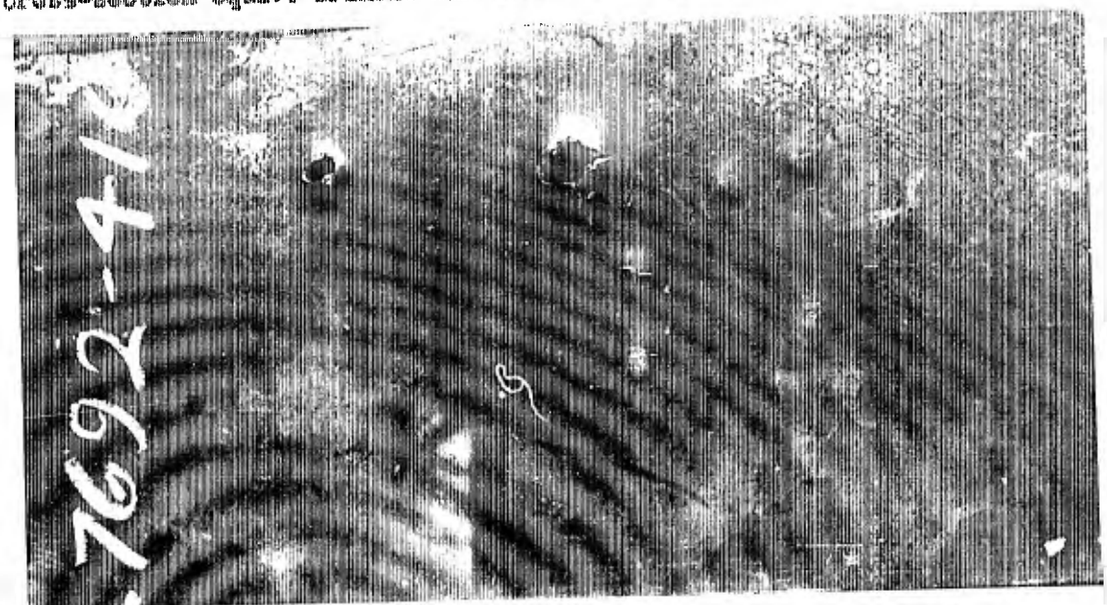
Fig. 160. Heat No. 7692-410. Back of plate - photographed 1/2 actual size. Cross-section equiv. Brinell hardness 332. Ballistic limit 2162 F/S.

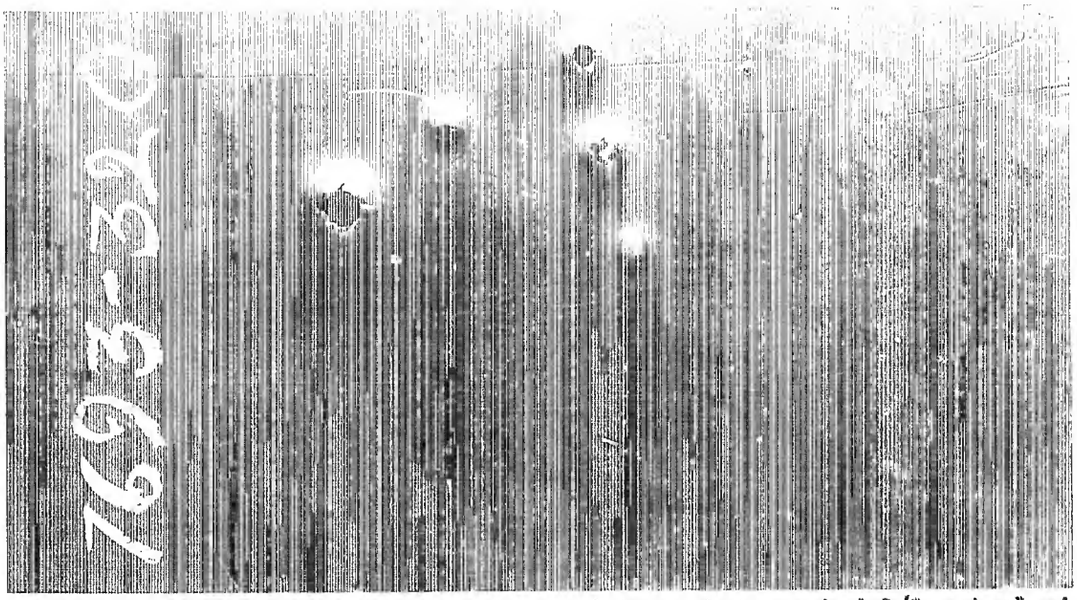
14604

Fig. 160. Same heat as shown above but at the 360 Brinell level. Cross-section equiv. Brinell hardness 362. Ballistic limit 2211 F/S.



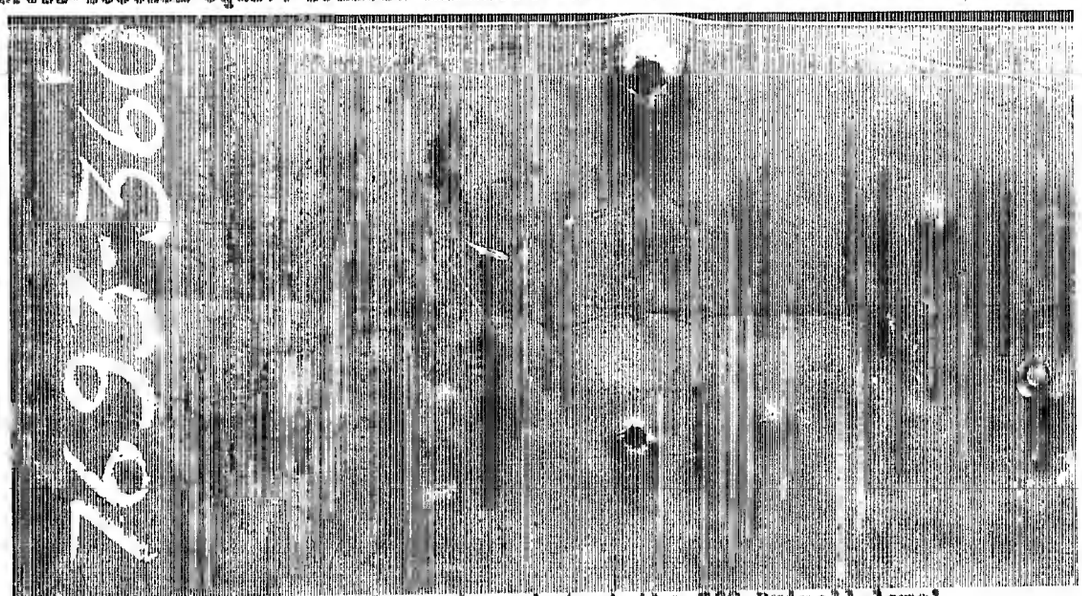
14673

Fig. 161. Same heat as shown above but at the 410 Brinell level. Cross-section equiv. Brinell hardness 416. Ballistic limit 2290 F/S.



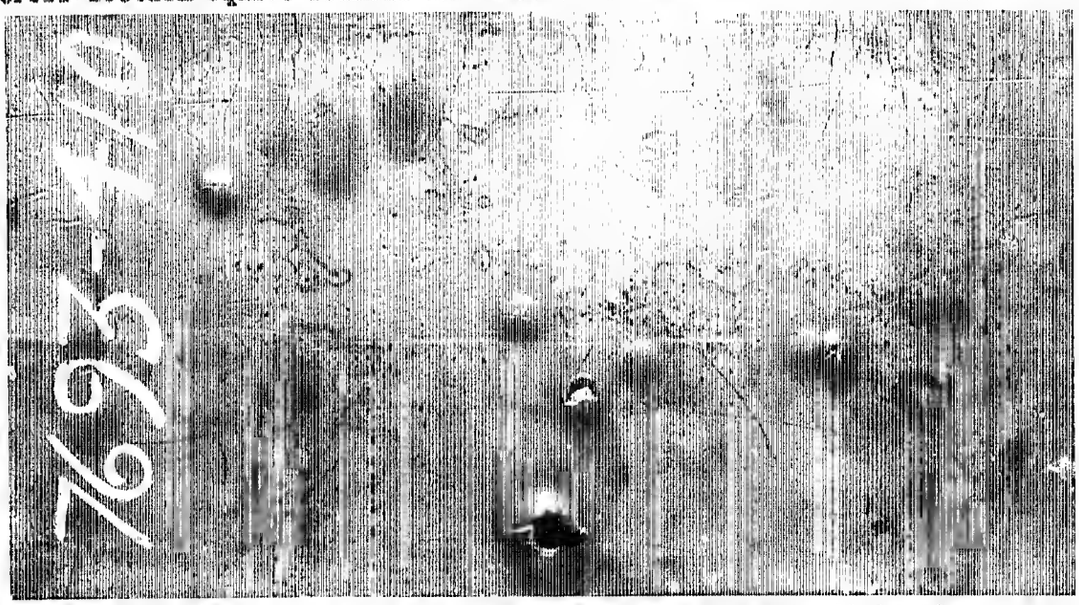
14574

Fig. 162. Heat No. 7693-320. Back of plate - photographed 1/2 actual size.
Cross-section equiv. Brinell hardness 327. Ballistic limit 2194 F/S.



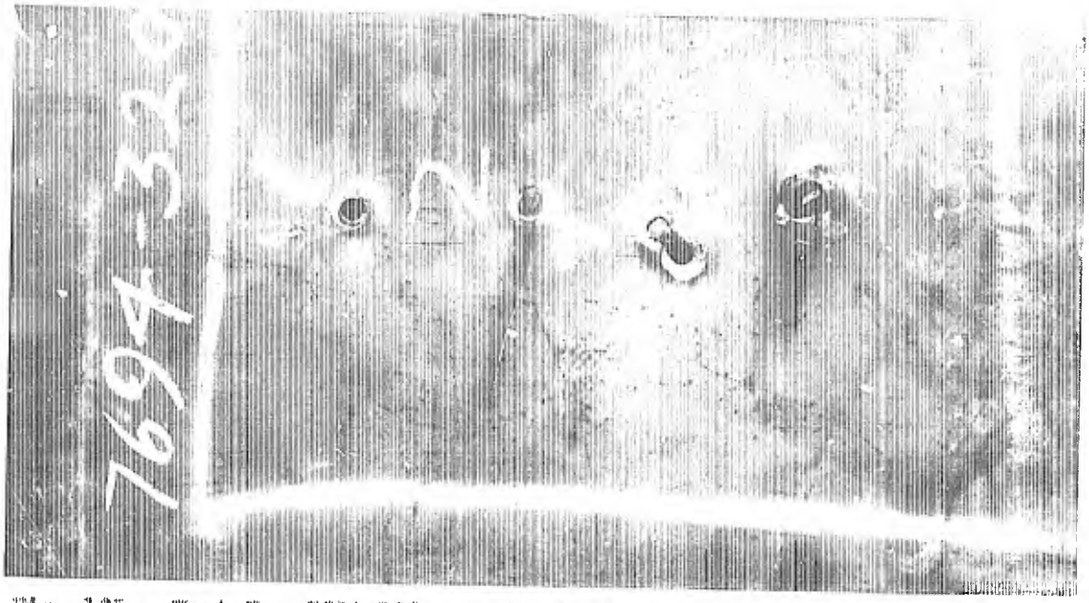
14550

Fig. 163. Same heat as shown above but at the 360 Brinell level.
Cross-section equiv. Brinell hardness 372. Ballistic limit 2304 F/S.



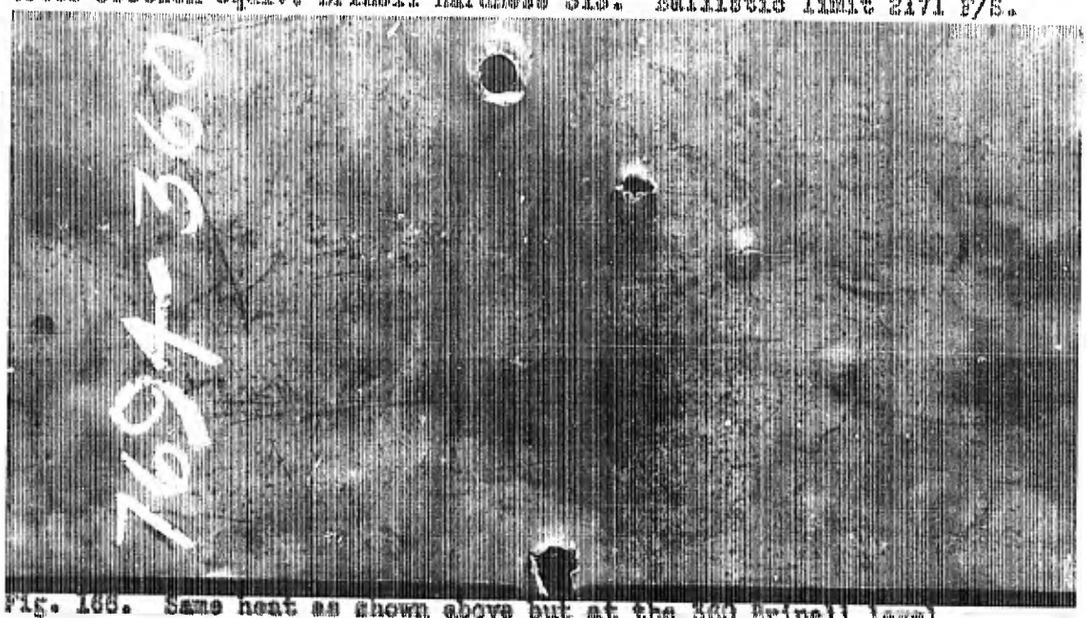
14536

Fig. 164. Same heat as shown above but at the 410 Brinell level.
Cross-section equiv. Brinell hardness 409. Ballistic limit 2319 F/S.



14564

Fig. 165. Heat No. 7694-320. Back of plate - photographed 1/2 actual size.
Cross-section equiv. Brinell hardness 313. Ballistic limit 2171 F/S.

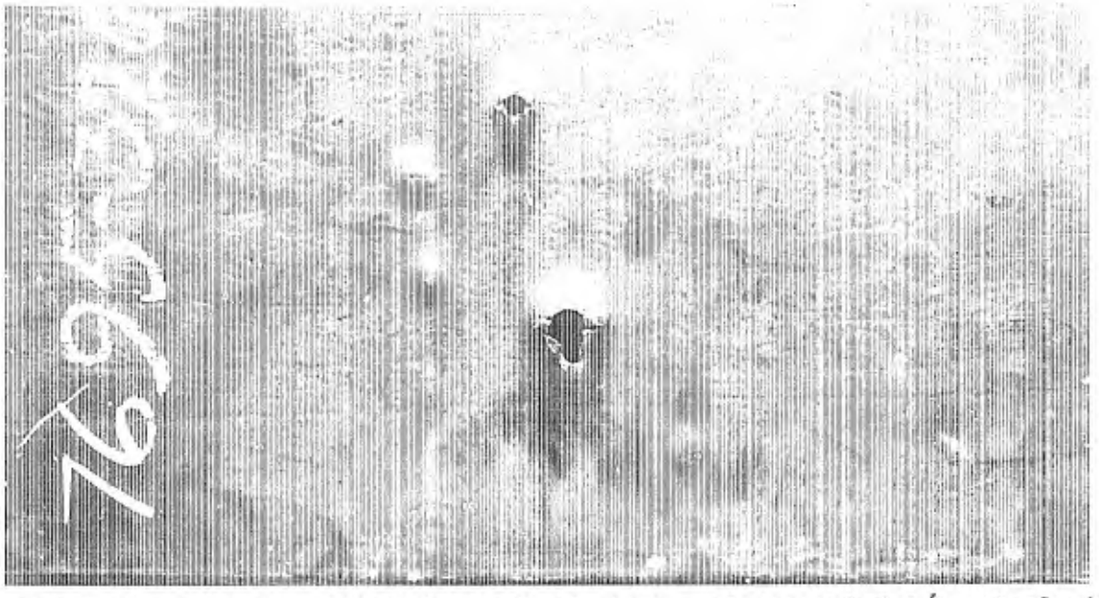


14579

Fig. 166. Same heat as shown above but at the 360 Brinell level.
Cross-section equiv. Brinell hardness 363. Ballistic limit 2253 F/S.

14560

Fig. 167. Same heat as shown above but at the 410 Brinell level.
Cross-section equiv. Brinell hardness 420. Ballistic limit 2300 F/S.



14559

Fig. 168. Heat No. 7695-320. Back of plate - photographed 1/2 actual size.
Cross-section equiv. Brinell hardness 322. Ballistic limit 2147 F/S.

14561

Fig. 169. Same heat as shown above but at the 360 Brinell level.
Cross-section equiv. Brinell hardness 366. Ballistic limit 2242 F/S.

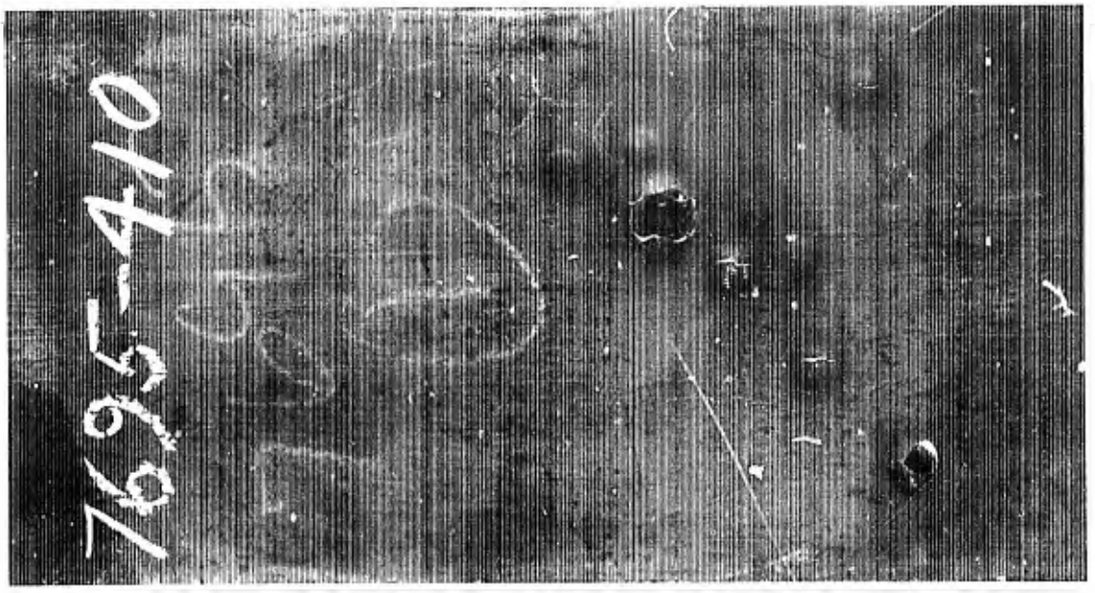


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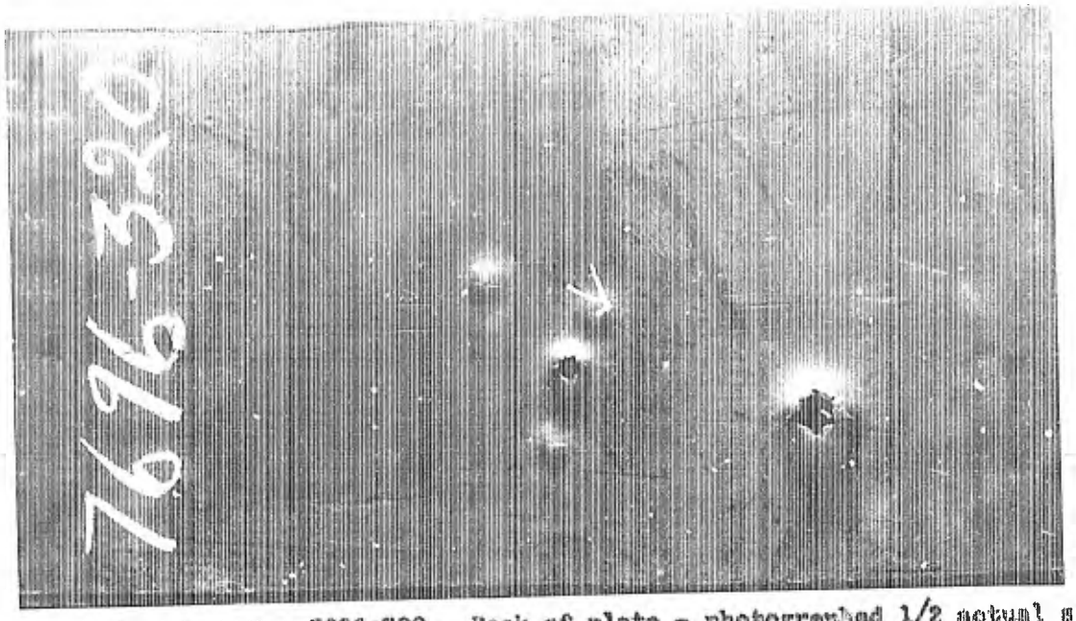
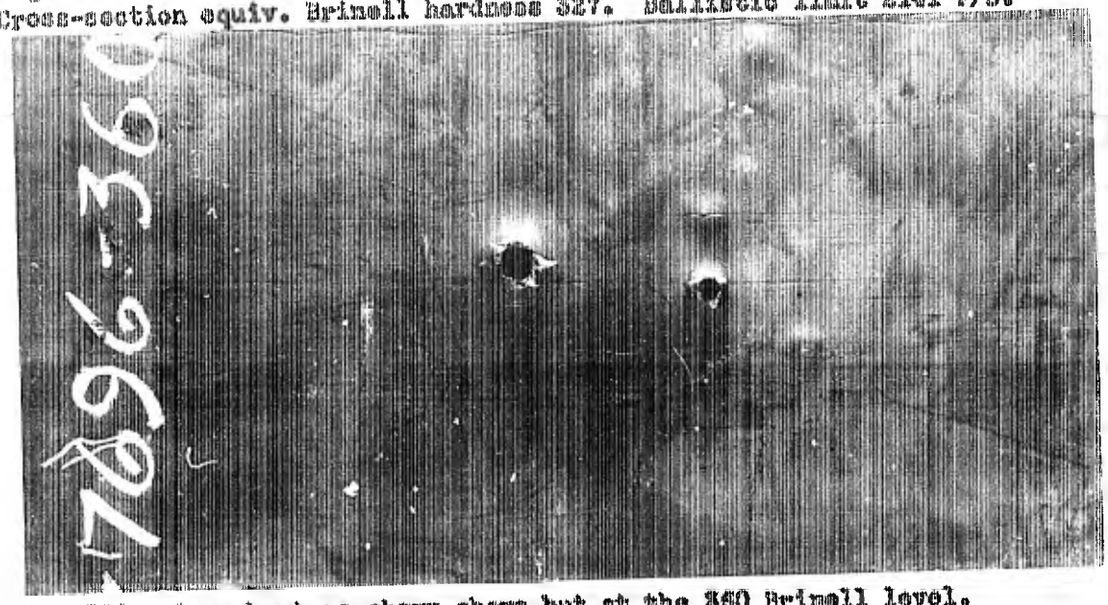
Fig. 170. Same heat as shown above but at the 410 Brinell level.
Cross-section equiv. Brinell hardness 413. Ballistic limit 2242 F/S.



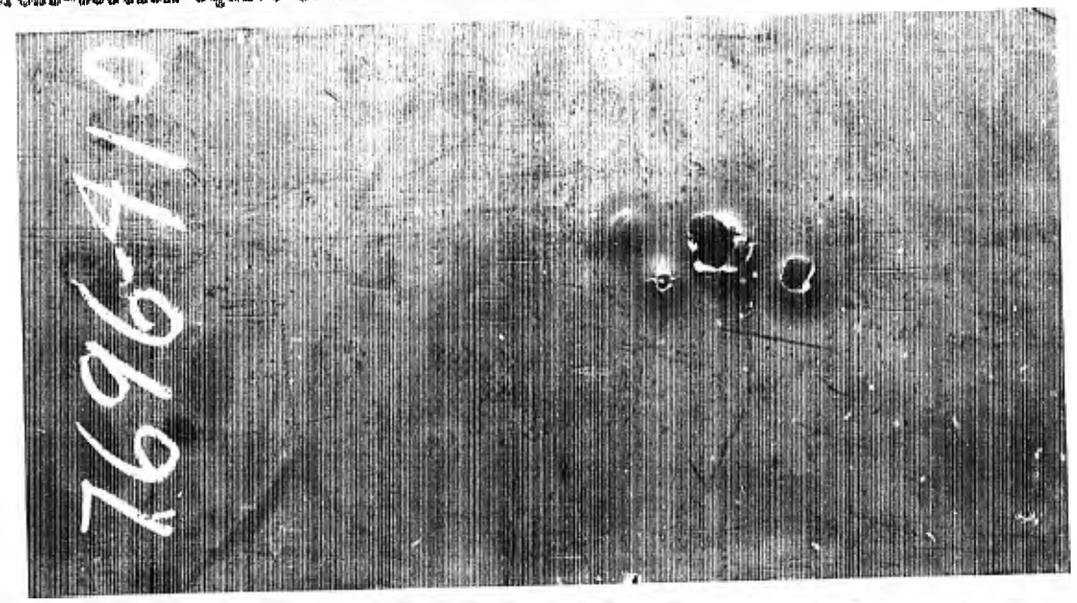
14543

Fig. 171. Heat No. 7696:320. Back of plate - photographed 1/2 actual size.
Cross-section equiv. Brinell hardness 327. Ballistic limit 2141 F/S.



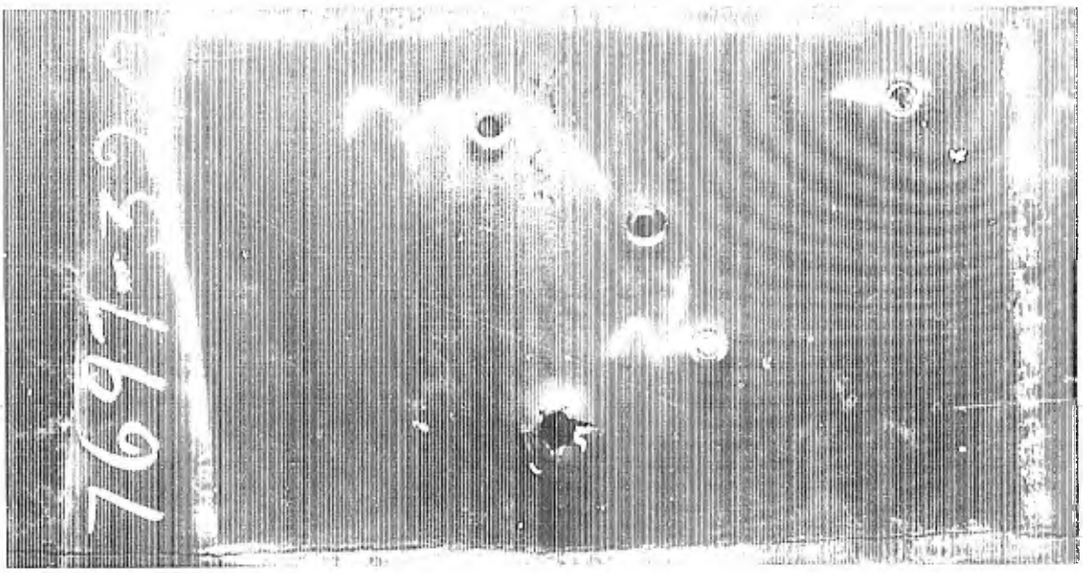
14563

Fig. 172. Same heat as shown above but at the 360 Brinell level.
Cross-section equiv. Brinell hardness 362. Ballistic limit 2247 F/S.



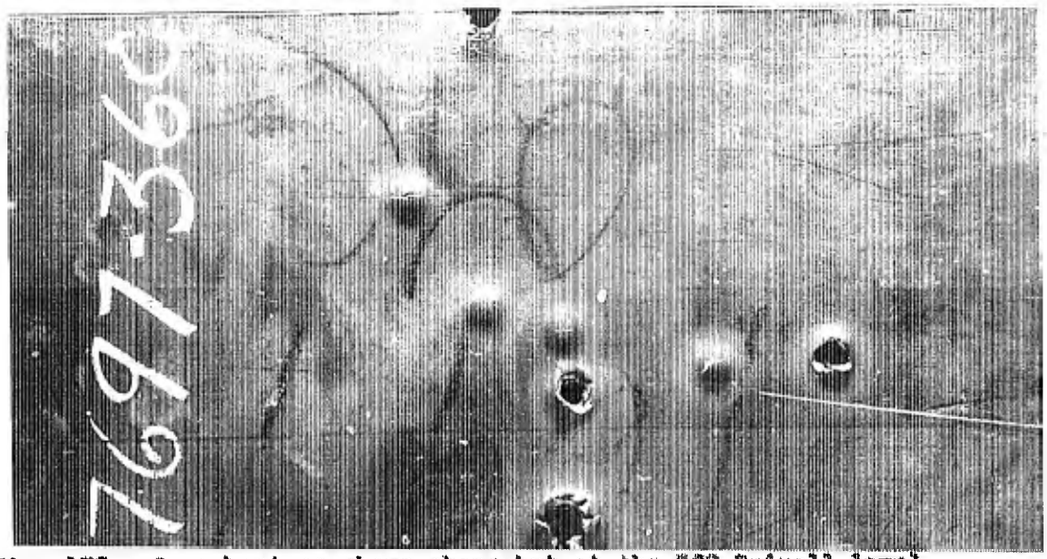
14646

Fig. 173. Same heat as shown above but at the 410 Brinell level.
Cross-section equiv. Brinell hardness 415. Ballistic limit 2372 F/S.



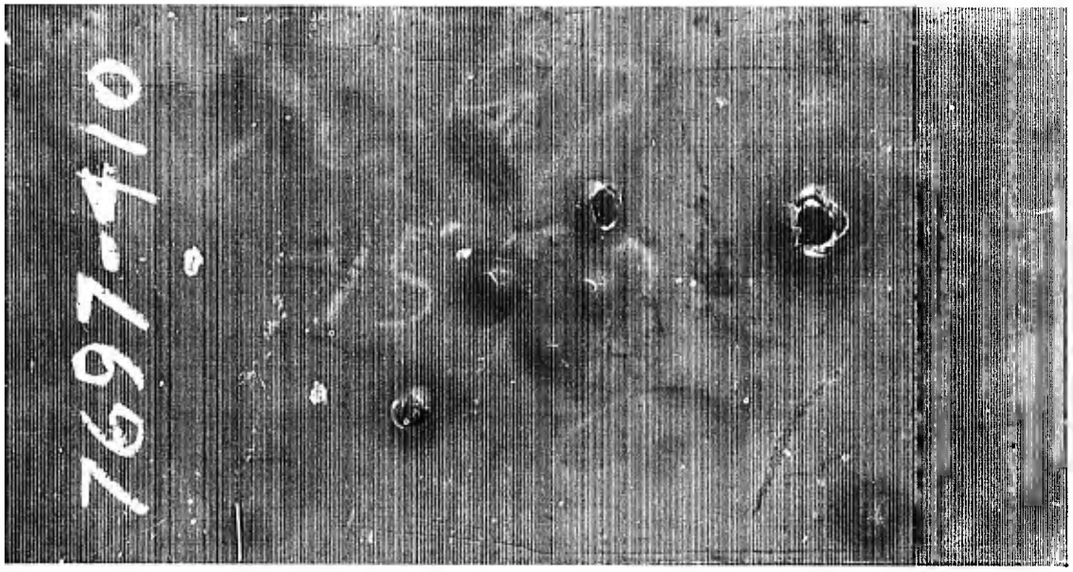
14553

Fig. 174. Heat No. 7697-330. Back of plate - photographed 1/2 actual size. Cross-section equiv. Brinell hardness 352. Ballistic limit 2124 F/S.



14543

Fig. 173. Same heat as shown above but at the 360 Brinell level. Cross-section equiv. Brinell hardness 372. Ballistic limit 2319 F/S.



14561

Fig. 176. Same heat as shown above but at the 410 Brinell level. Cross-section equiv. Brinell hardness 428. Ballistic limit 2413 F/S.

14590

Fig. 177. Heat No. 7702-320. Back of plate - photographed 1/2 actual size.
Cross-section equiv. Brinell hardness 327. Ballistic limit 2186 F/S.

14598

Fig. 178. Same heat as shown above but at the 360 Brinell level.
Cross-section equiv. Brinell hardness 362. Ballistic limit 2226 F/S.

14606

Fig. 179. Same heat as shown above but at the 410 Brinell level.
Cross-section equiv. Brinell hardness 415. Ballistic limit 2337 F/S.

14533

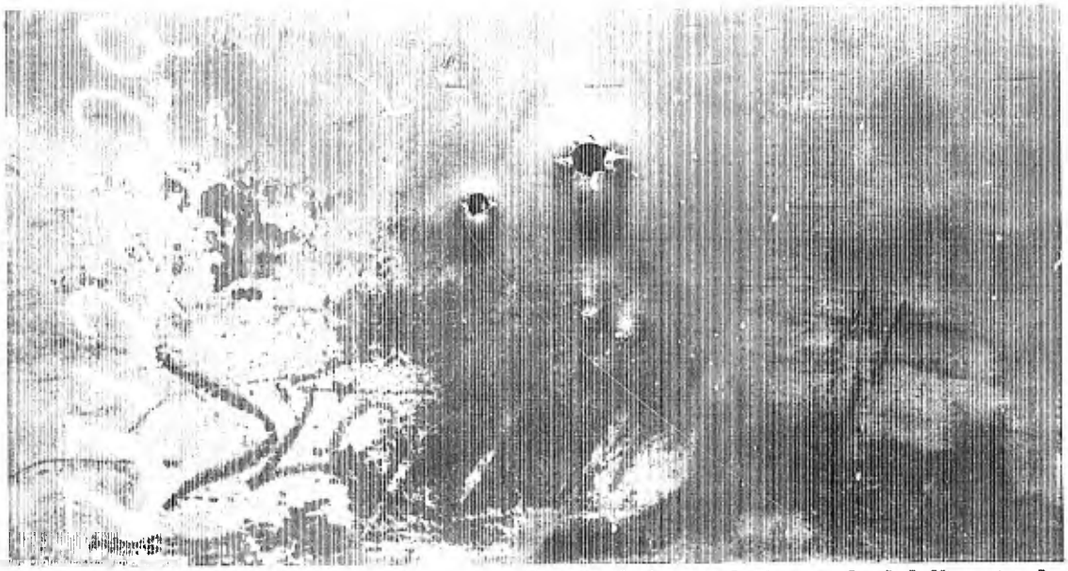
Fig. 180. Heat No. 7TM-320. Back of plate - photographed 1/2 actual size.
Cross-section equiv. Brinell hardness 317. Ballistic limit 2156 F/S.

14600

Fig. 181. Same heat as shown above but at the 360 Brinell level.
Cross-section equiv. Brinell hardness 362. Ballistic limit 2256 F/S.

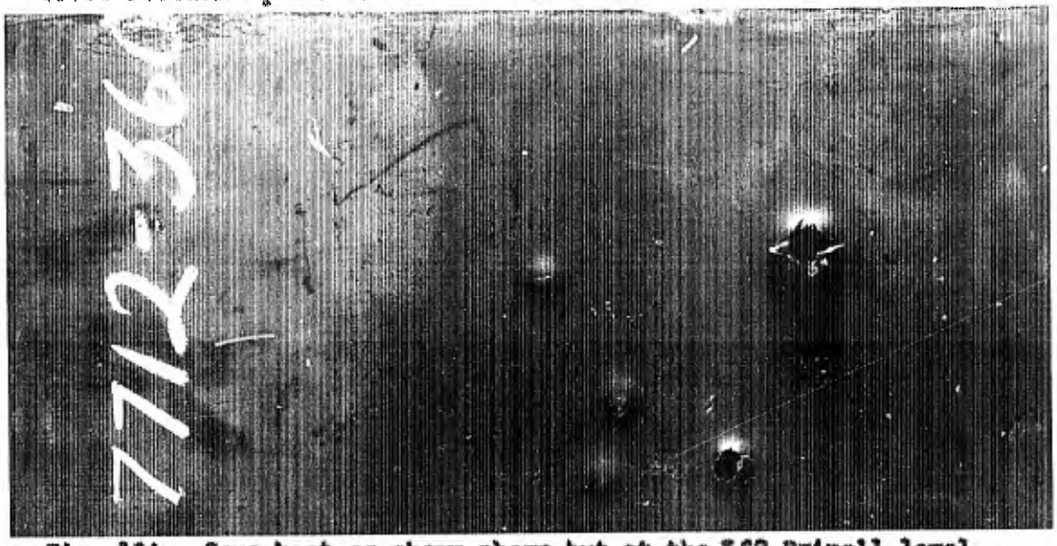
14540

Fig. 182. Same heat as shown above but at the 410 Brinell level.
Cross-section equiv. Brinell hardness 415. Ballistic limit 2420 F/S.



14568

Fig. 183. Heat No. 7712G520. Back of plate - photographed 1/2 actual size. Cross-section equiv. Brinell hardness 317. Ballistic limit 2119 F/S.

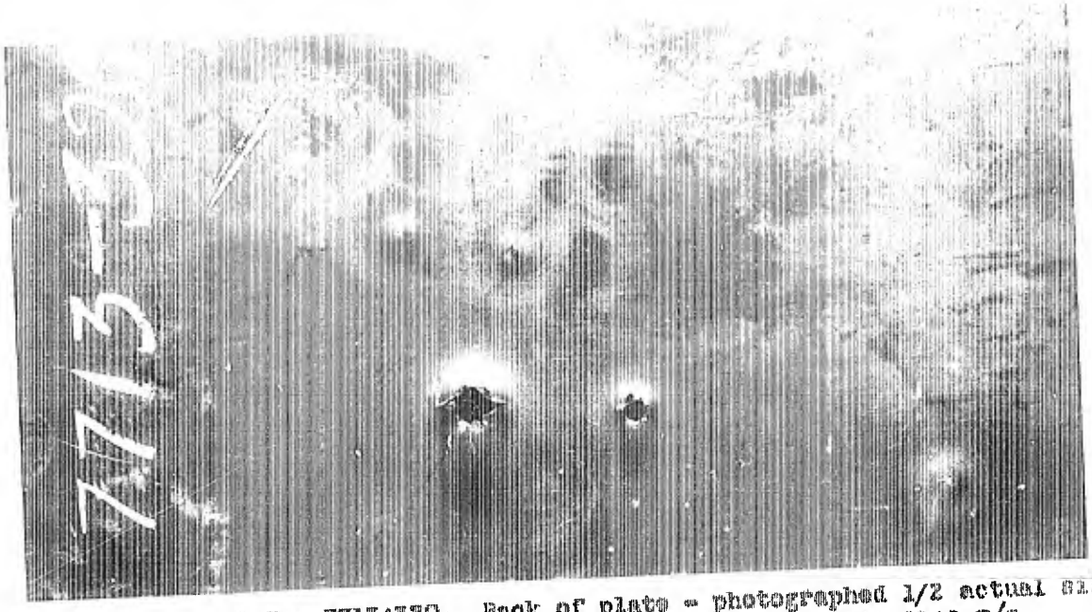


14551

Fig. 184. Same heat as shown above but at the 360 Brinell level. Cross-section equiv. Brinell hardness 382. Ballistic limit 2304 F/S.

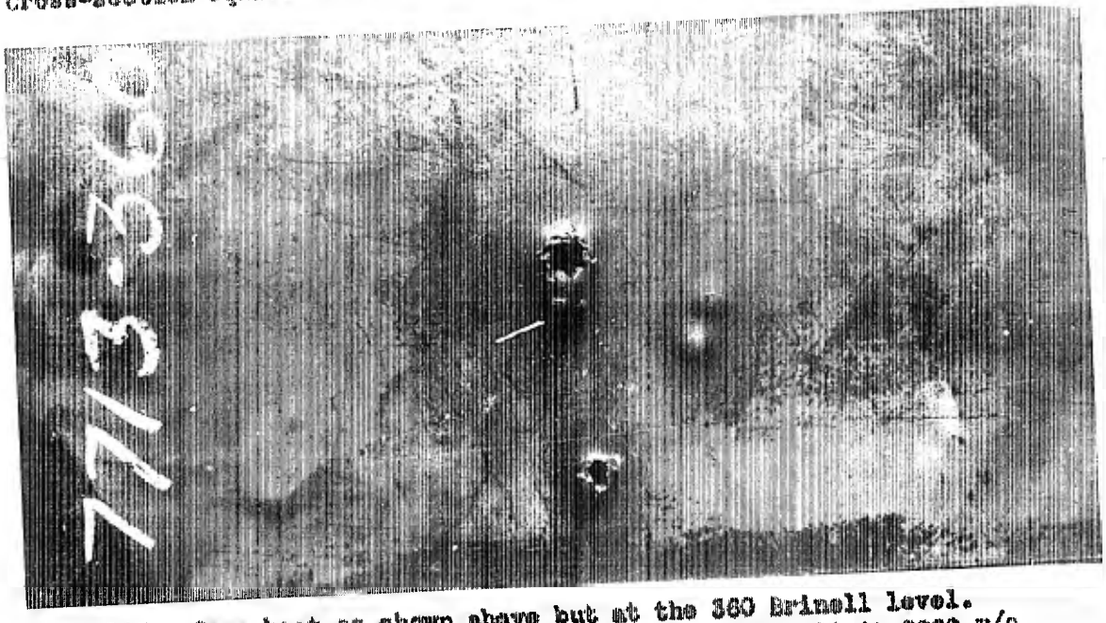
14602

Fig. 185. Same heat as shown above but at the 410 Brinell level. Cross-section equiv. Brinell hardness 404. Ballistic limit 2402 F/S.



14570

Fig. 186. Heat No. 7715-4320. Back of plate - photographed 1/2 actual size. Cross-section equiv. Brinell hardness 332. Ballistic limit 2148 F/S.

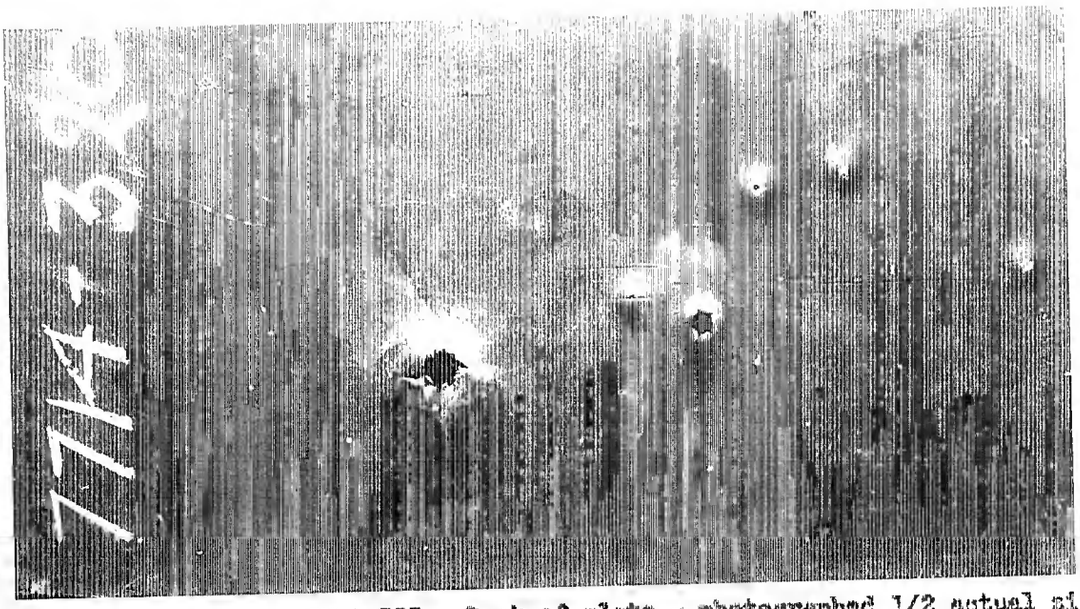


14576

Fig. 187. Same heat as shown above but at the 360 Brinell level. Cross-section equiv. Brinell hardness 372. Ballistic limit 2220 F/S.

14585

Fig. 188. Same heat as shown above but at the 410 Brinell level. Cross-section equiv. Brinell hardness 426. Ballistic limit 2533 F/S.



14544

Fig. 188. Heat No. 7714-320. Back of plate - photographed 1/2 actual size. Cross-section equiv. Brinell hardness 315. Ballistic limit 2178 F/S.

14554

Fig. 190. Same heat as shown above but at the 360 Brinell level. Cross-section equiv. Brinell hardness 342. Ballistic limit 2269 F/S.

14560

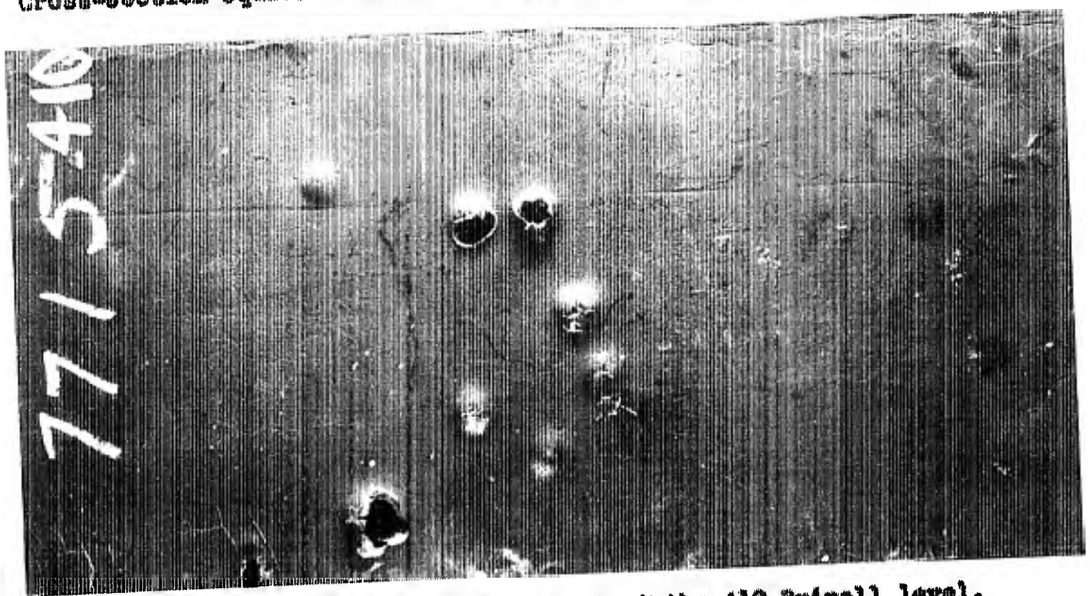
Fig. 191. Same heat as shown above but at the 410 Brinell level. Cross-section equiv. Brinell hardness 415. Ballistic limit 2382 F/S.

14606

Fig. 102. Heat No. 7715-320. Back of plate - photographed 1/2 actual size.
Cross-section equiv. Brinell hardness 352. Ballistic limit 2176 F/S.

14607

Fig. 103. Same heat as shown above but at the 360 Brinell level.
Cross-section equiv. Brinell hardness 367. Ballistic limit 2240 F/S.

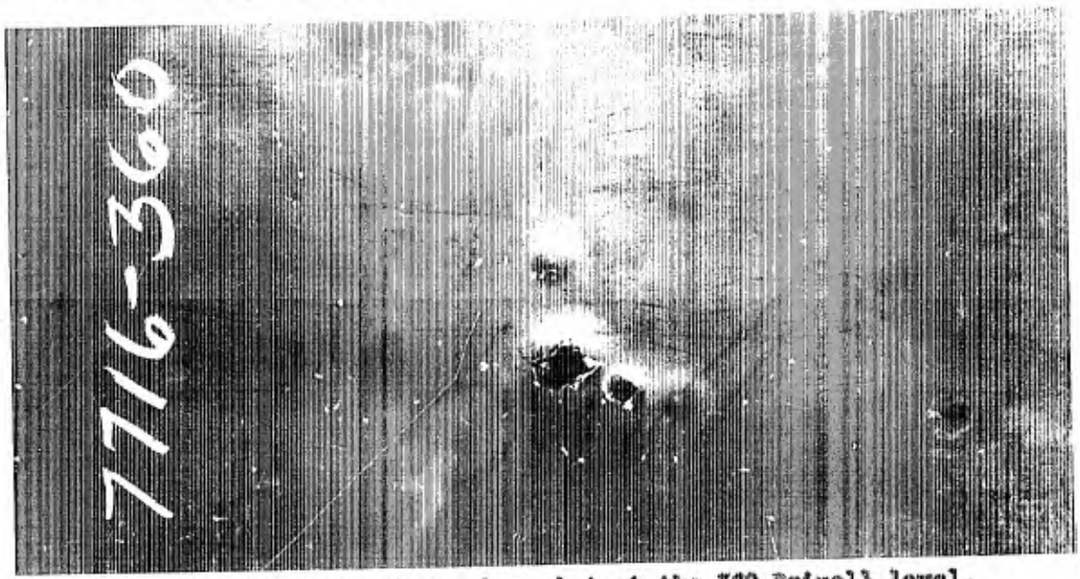


14605

Fig. 104. Same heat as shown above but at the 410 Brinell level.
Cross-section equiv. Brinell hardness 416. Ballistic limit 2336 F/S.

14587

Fig. 195. Heat No. 7716:320. Back of plate - photographed 1/2 actual size.
Cross-section equiv. Brinell hardness 322. Ballistic limit 2206 F/S.



14586

Fig. 196. Same heat as shown above but at the 360 Brinell level.
Cross-section equiv. Brinell hardness 377. Ballistic limit 2264 F/S.

14585

Fig. 197. Same heat as shown above but at the 410 Brinell level.
Cross-section equiv. Brinell hardness 415. Ballistic limit 2363 F/S.

14556

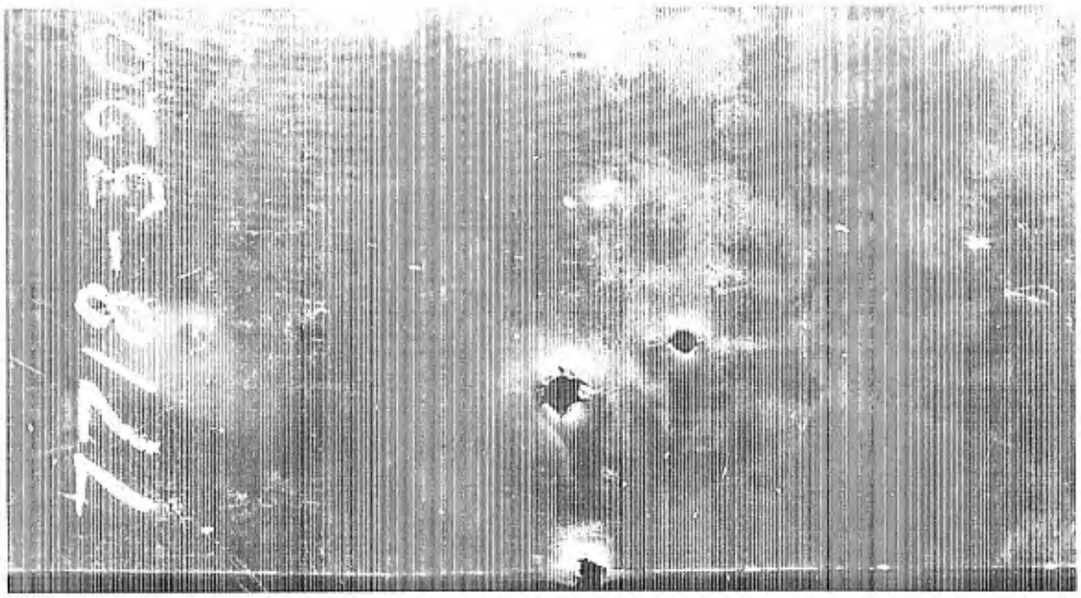
Fig. 198. Heat No. 7717:320. Back of plate - photographed 1/2 actual size.
Cross-section equiv. Brinell hardness 322. Ballistic limit 2246 F/S.

14550

Fig. 199. Same heat as shown above but at the 360 Brinell level.
Cross-section equiv. Brinell hardness 372. Ballistic limit 2274 F/S.

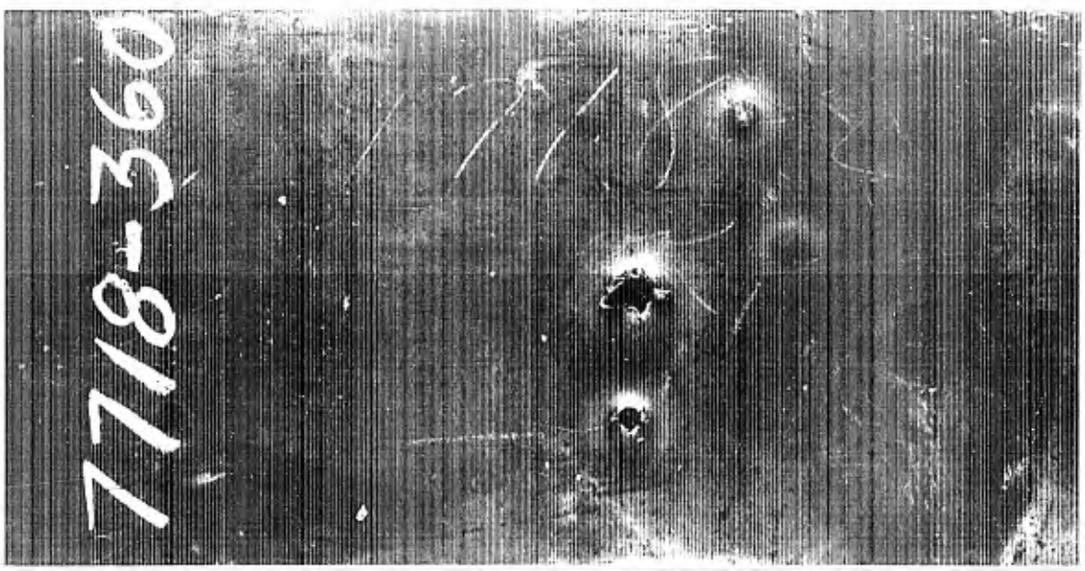
14560

Fig. 200. Same heat as shown above but at the 410 Brinell level.
Cross-section equiv. Brinell hardness 415. Ballistic limit 2389 F/S.



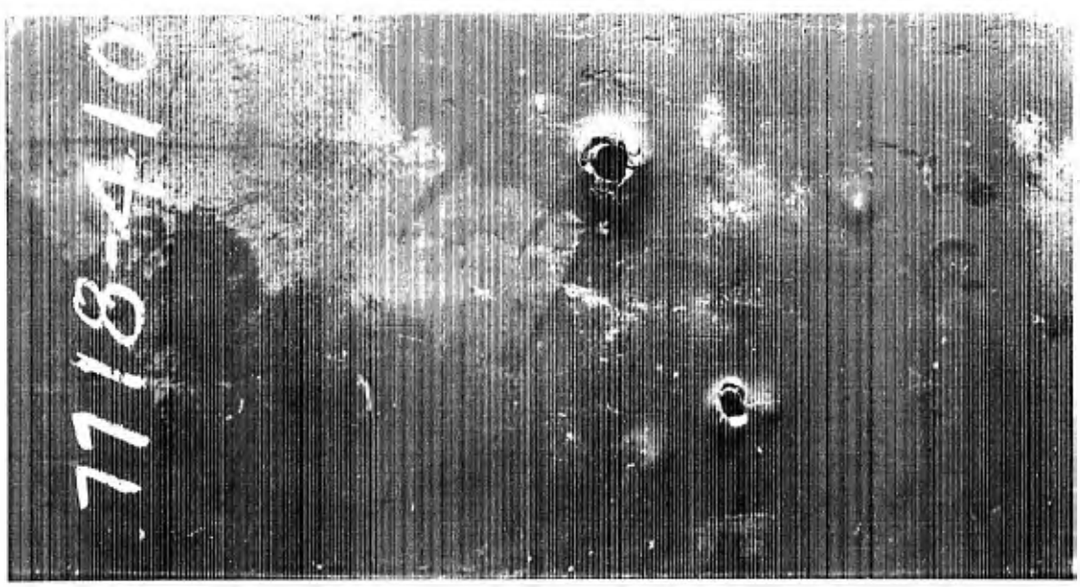
14551

Fig. 201. Heat No. 7718-320. Back of plate - photographed 1/2 actual size.
Cross-section equiv. Brinell hardness 518. Ballistic limit 2106 F/S.



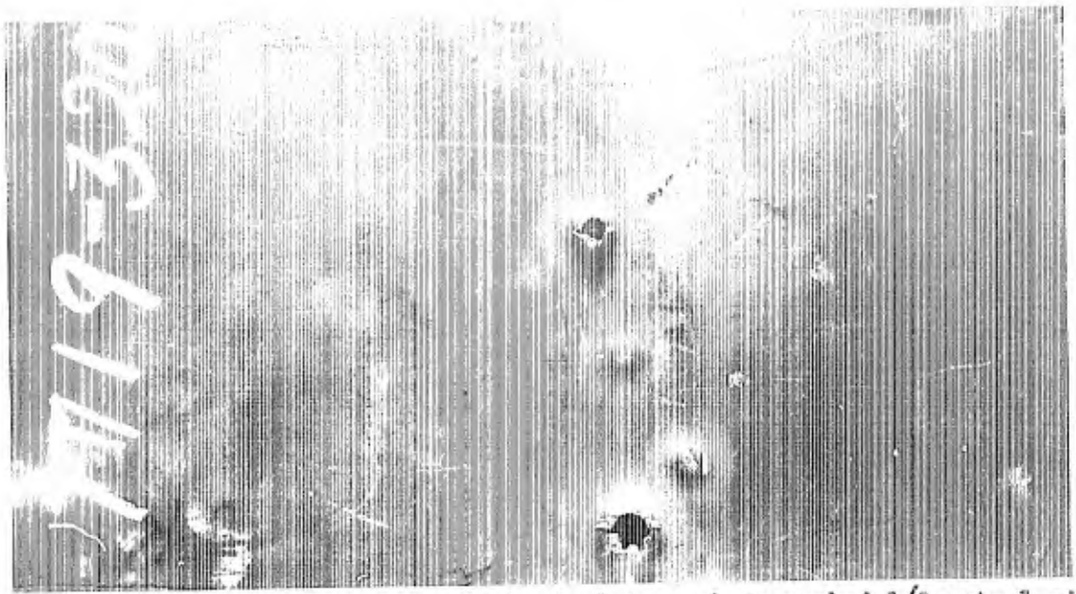
14557

Fig. 202. Same heat as shown above but at the 360 Brinell level.
Cross-section equiv. Brinell hardness 357. Ballistic limit 2266 F/S.



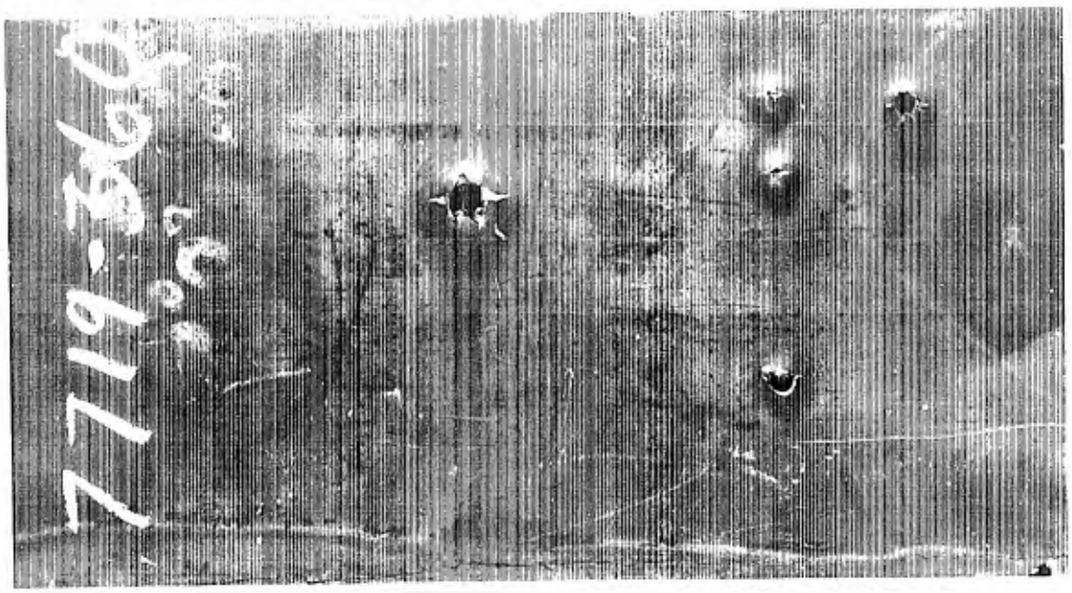
14548

Fig. 203. Same heat as shown above but at the 410 Brinell level.
Cross-section equiv. Brinell hardness 415. Ballistic limit 2314 F/S.



14571

Fig. 204. Heat No. 7719:320. Back of plate - photographed 1/2 actual size.
Cross-section equiv. Brinell hardness 313. Ballistic limit 2171 F/S.

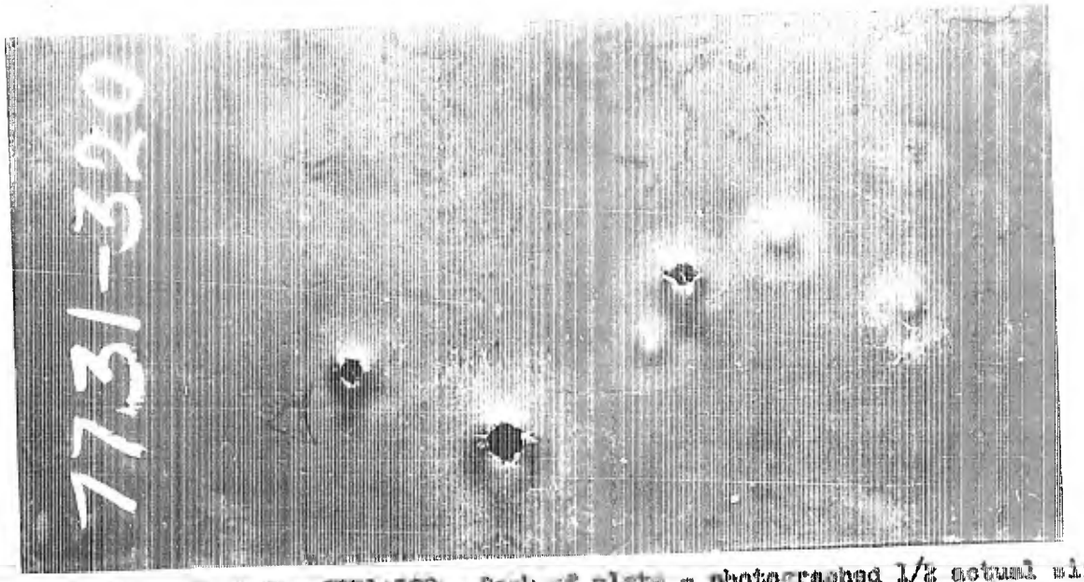


14568

Fig. 205. Same heat as shown above but at the 360 Brinell level.
Cross-section equiv. Brinell hardness 357. Ballistic limit 2338 F/S.

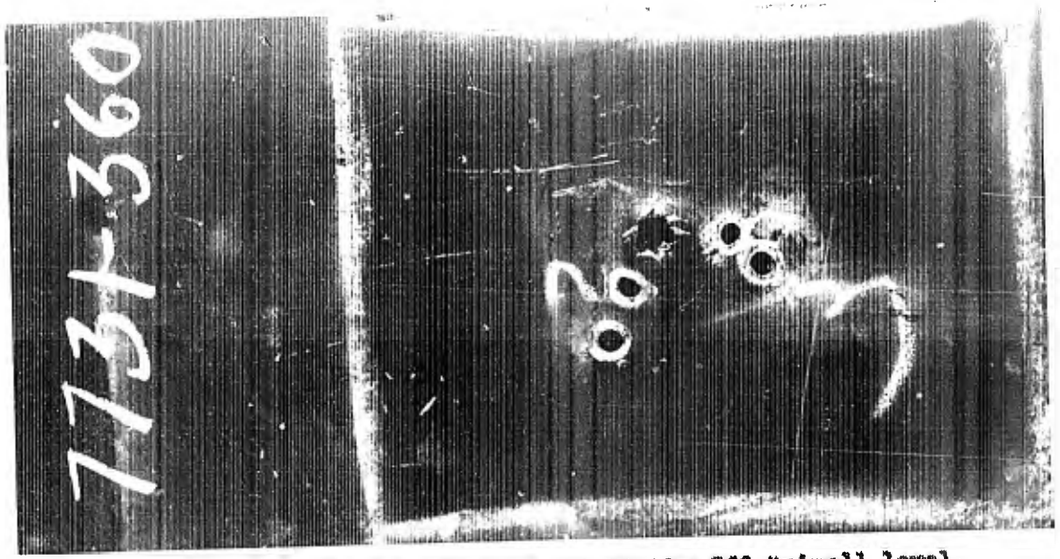
14541

Fig. 206. Same heat as shown above but at the 410 Brinell level.
Cross-section equiv. Brinell hardness 426. Ballistic limit 2377 F/S.



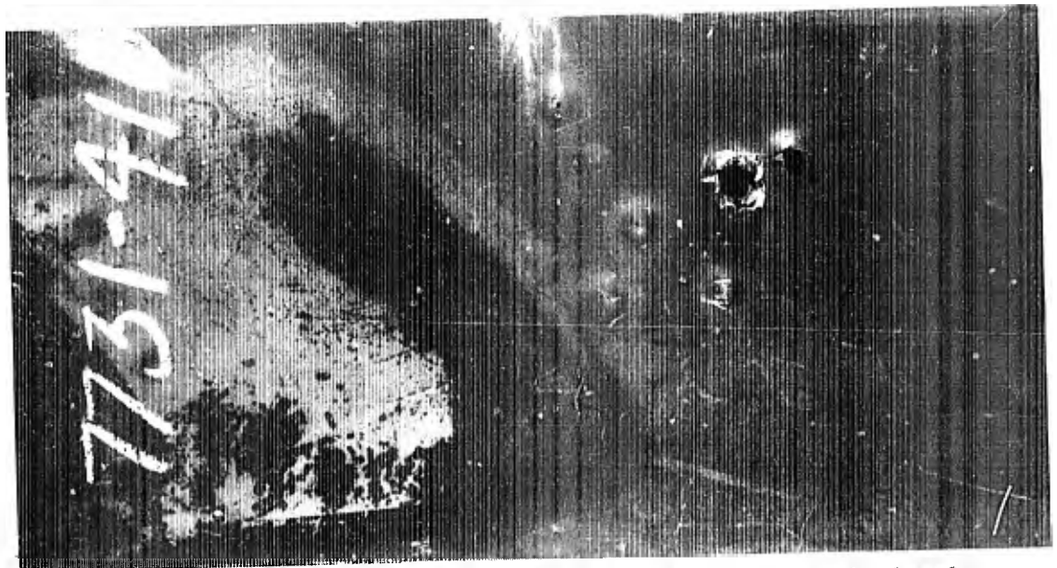
14562

Fig. 207. Heat No. 7731-320. Back of plate - photographed 1/2 actual size. Cross-section equiv. Brinell hardness 313. Ballistic limit 2144 F/S.



14564

Fig. 208. Same heat as shown above but at the 360 Brinell level. Cross-section equiv. Brinell hardness 365. Ballistic limit 2258 F/S.



14569

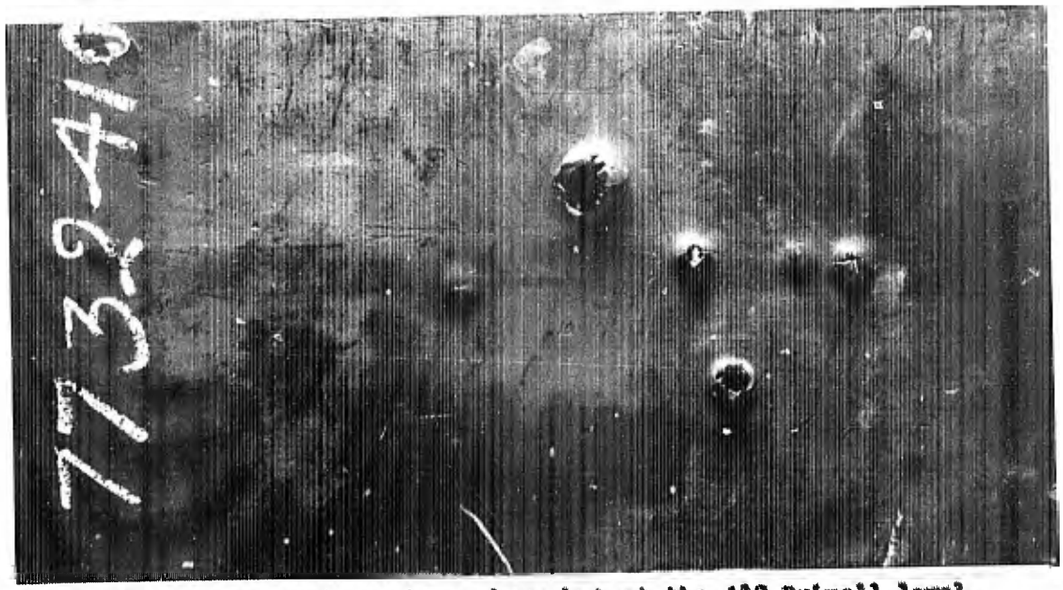
Fig. 209. Same heat as shown above but at the 410 Brinell level. Cross-section equiv. Brinell hardness 415. Ballistic limit 2378F/S.

14525

Fig. 210. Heat No. 7732-320. Back of plate - photographed 1/2 actual size.
Cross-section equiv. Brinell hardness 327. Ballistic limit 2136 F/S.

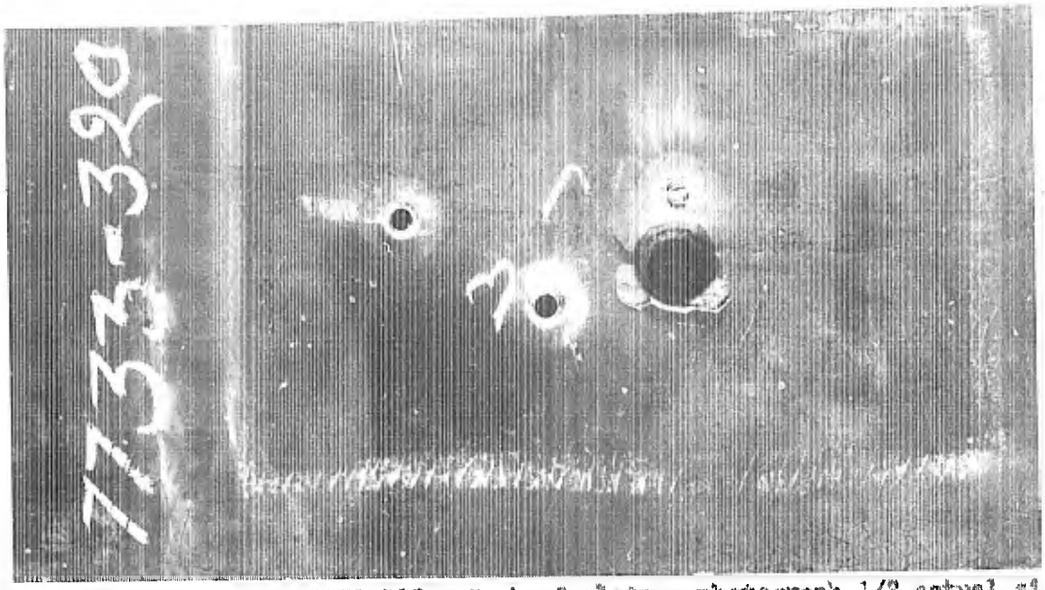
14539

Fig. 211. Same heat as shown above but at the 360 Brinell level.
Cross-section equiv. Brinell hardness 362. Ballistic limit 2232 F/S.



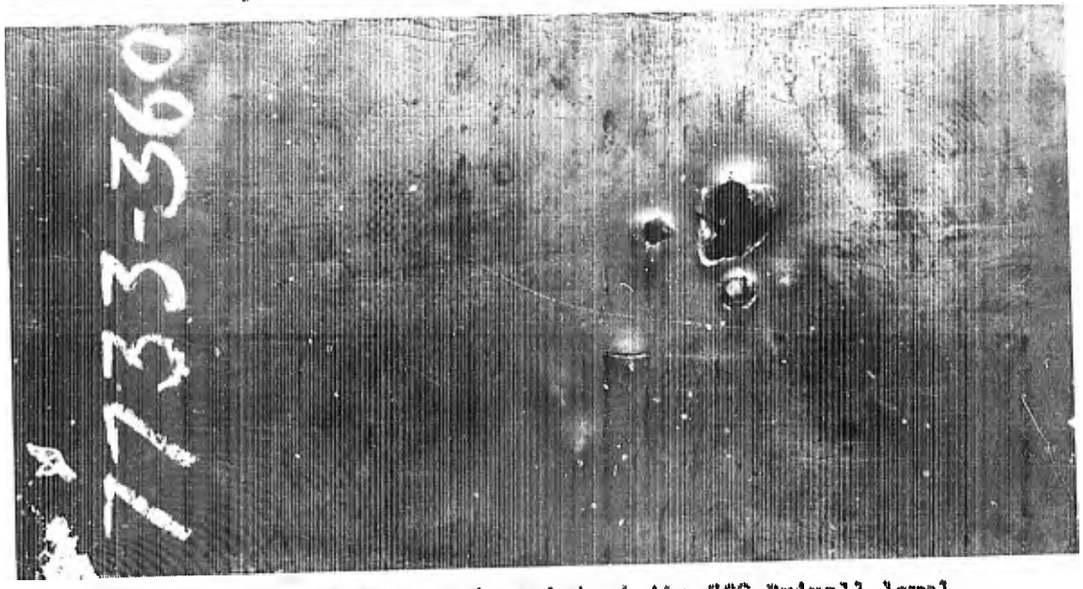
14538

Fig. 212. Same heat as shown above but at the 410 Brinell level.
Cross-section equiv. Brinell hardness 426. Ballistic limit 2380 F/S.



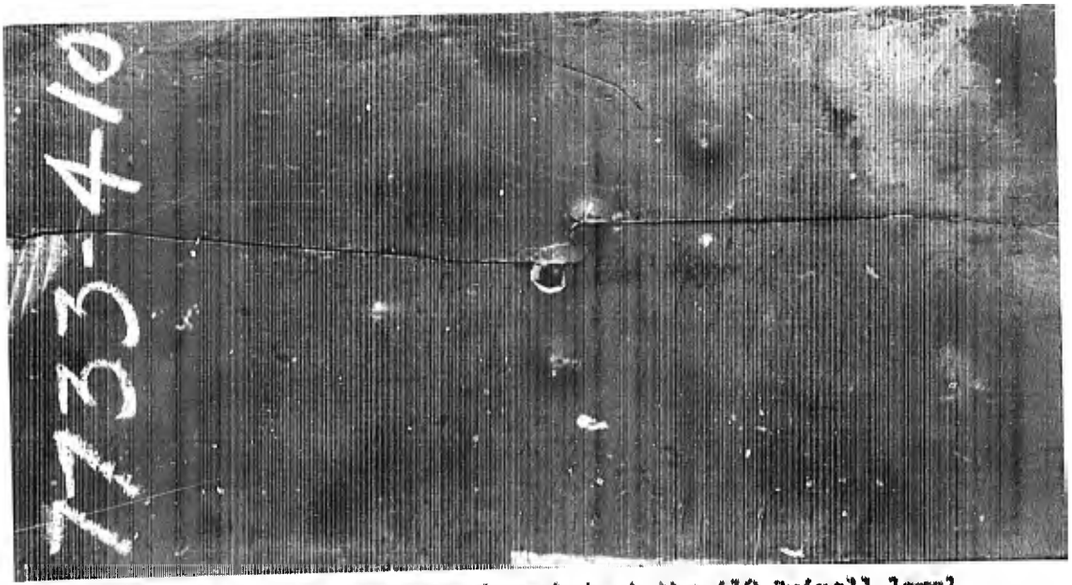
14530

Fig. 213. Heat No. 7733-330. Back of plate - photograph 1/2 actual size.
Cross-section equiv. Brinell hardness 322. Ballistic limit 2144 F/S.



14601

Fig. 214. Same heat as shown above but at the 360 Brinell level.
Cross-section equiv. Brinell hardness 372. Ballistic limit 2139 F/S.

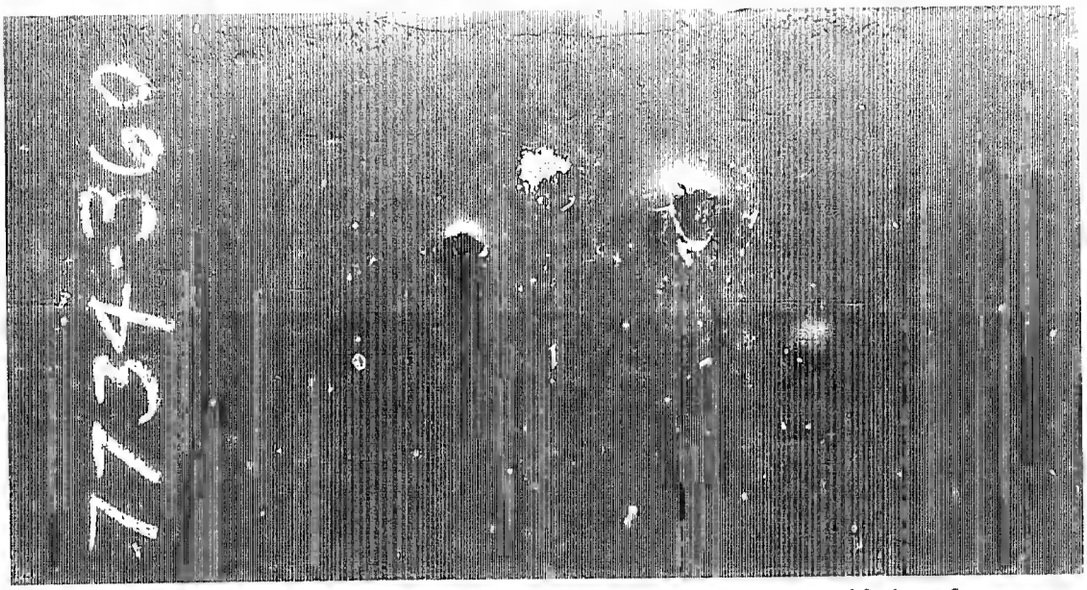


14603

Fig. 215. Same heat as shown above but at the 410 Brinell level.
Cross-section equiv. Brinell hardness 404. Ballistic limit 2287 F/S.

14545

Fig. 216. Heat No. 7754:320. Back of plate - photograph 1/2 actual size. Cross-section equiv. Brinell hardness 316. Ballistic limit 2188 F/S.



14591

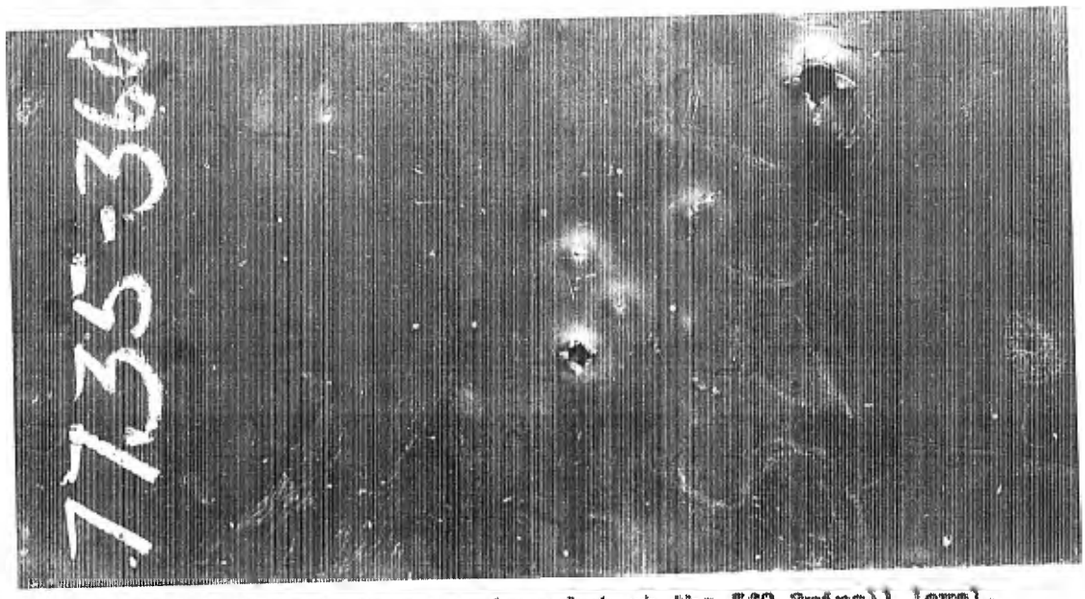
Fig. 217. Same heat as shown above but at the 360 Brinell level. Cross-section equiv. Brinell hardness 362. Ballistic limit 2267 F/S.

14556

Fig. 218. Same heat as shown above but at the 410 Brinell level. Cross-section equiv. Brinell hardness 404. Ballistic limit 2389 F/S.

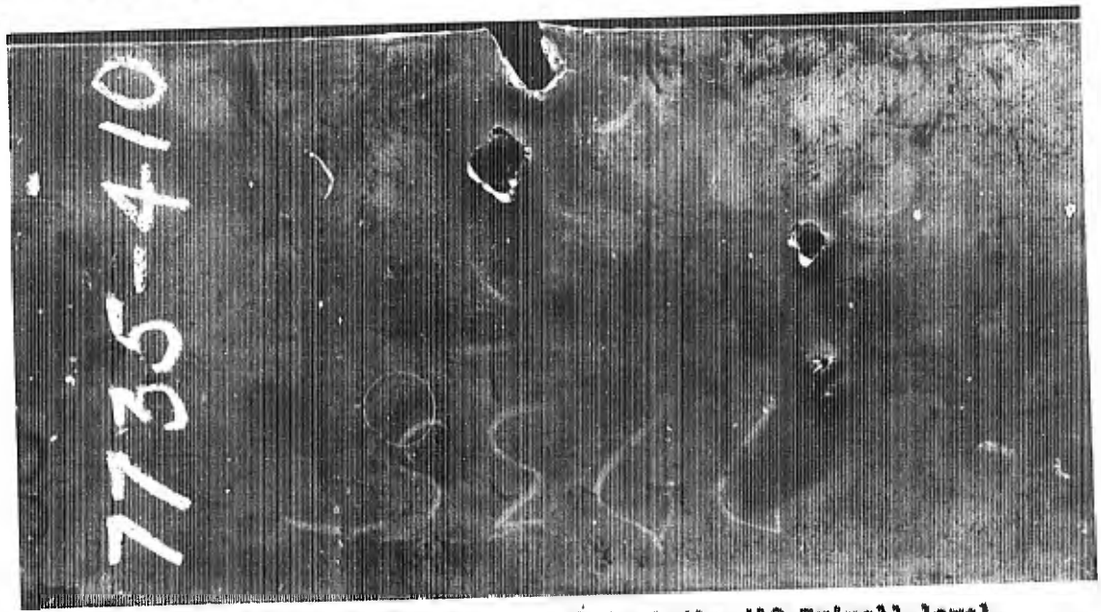
14593

Fig. 219. Heat No. 7735-320. Back of plate - photograph 1/2 actual size. Cross-section equiv. Brinell hardness 332. Ballistic limit 2159 F/S.



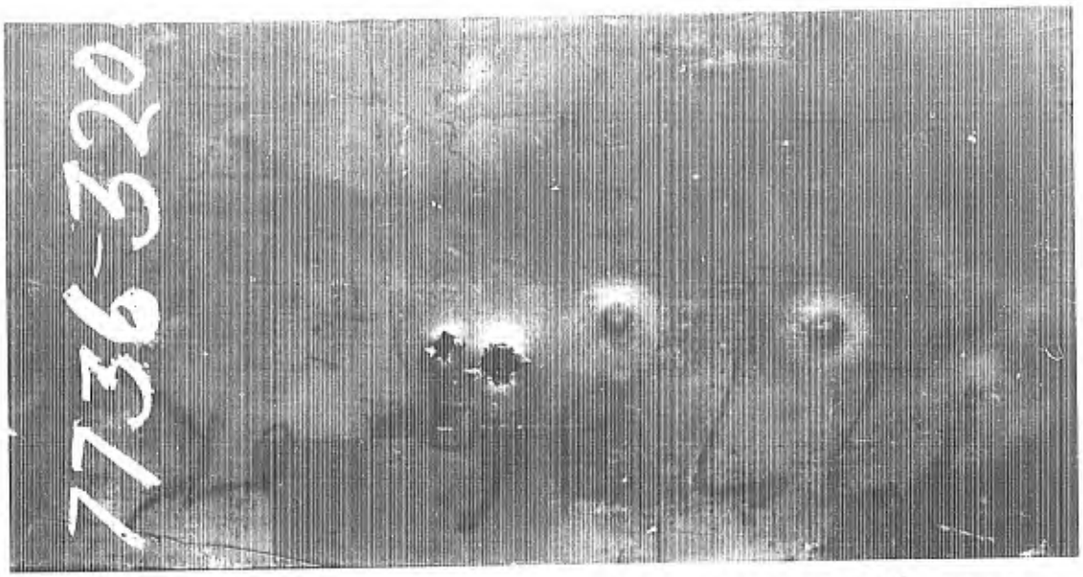
14527

Fig. 220. Same heat as shown above but at the 360 Brinell level. Cross-section equiv. Brinell hardness 372. Ballistic limit 2267 F/S.



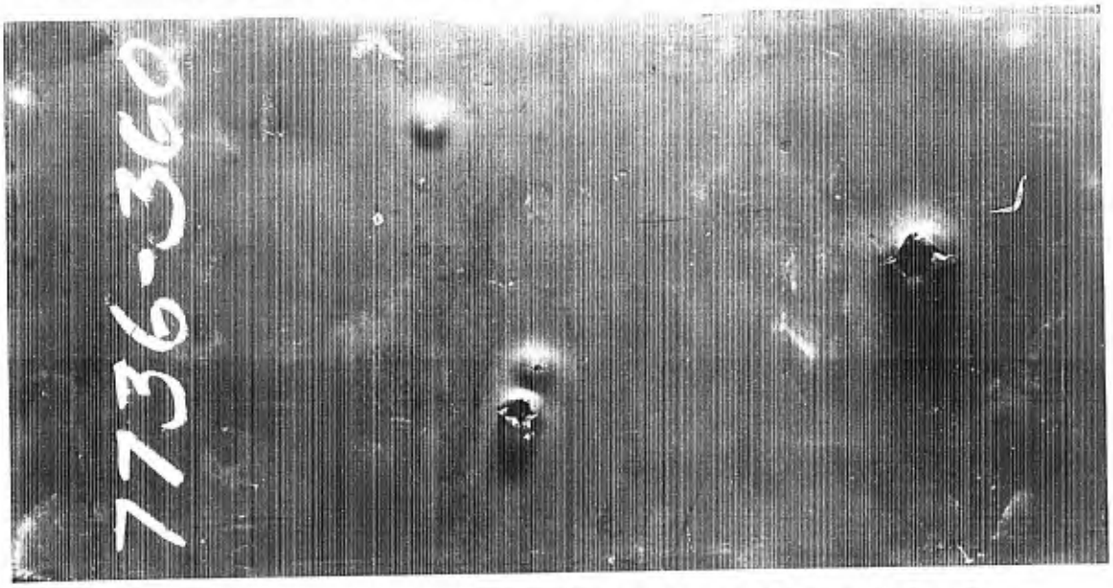
14595

Fig. 221. Same heat as shown above but at the 410 Brinell level. Cross-section equiv. Brinell hardness 404. Ballistic limit 2366 F/S.



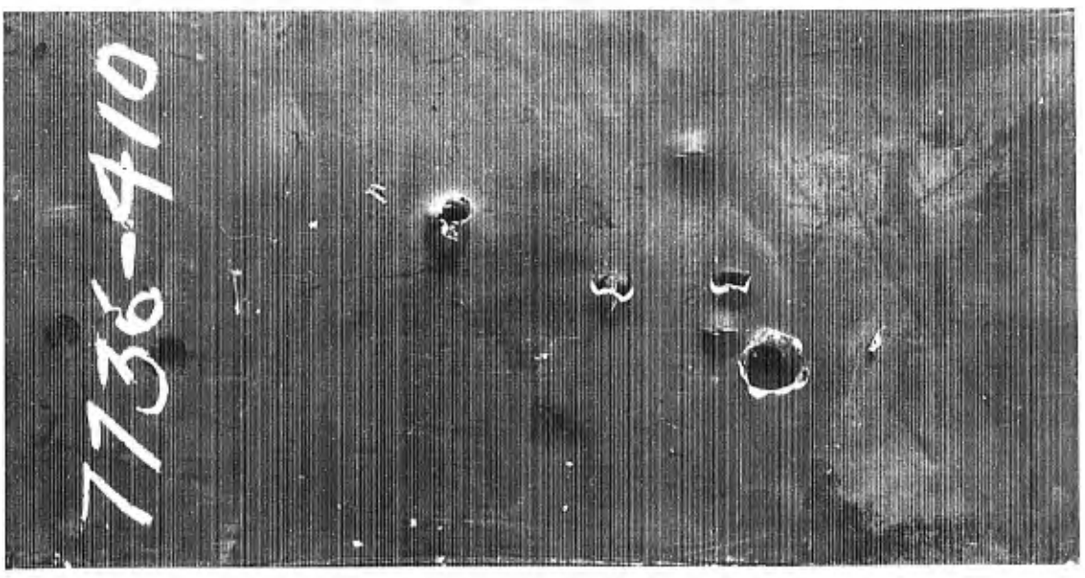
14534

Fig. 222. Heat No. 7736:320. Back of plate - photograph 1/2 actual size. Cross-section equiv. Brinell hardness 327. Ballistic limit 2134 F/S.



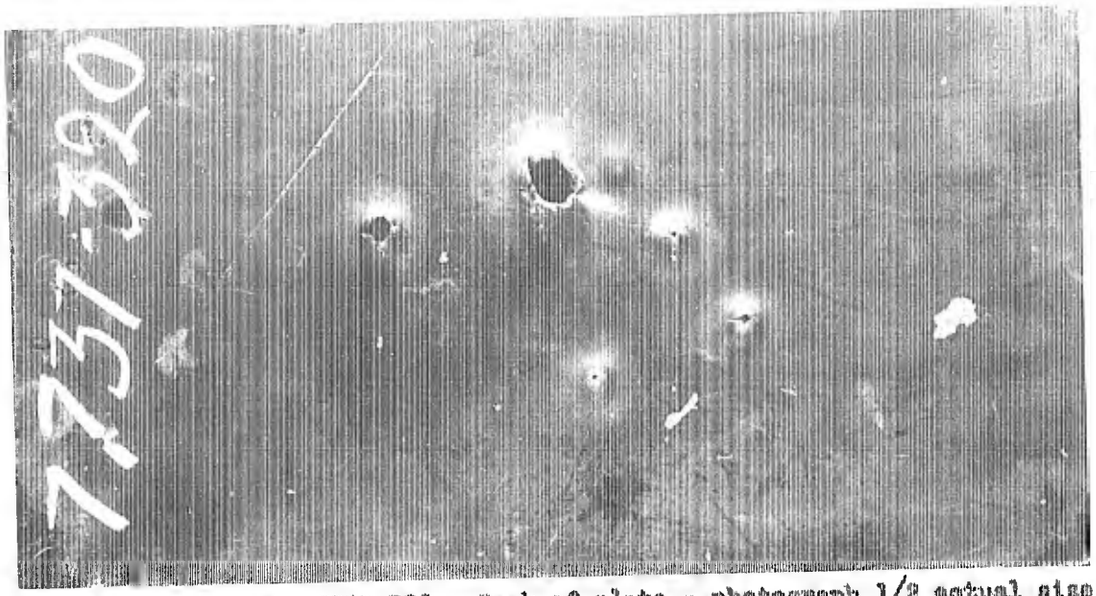
14572

Fig. 223. Same heat as shown above but at the 360 Brinell level. Cross-section equiv. Brinell hardness 372. Ballistic limit 2261 F/S.



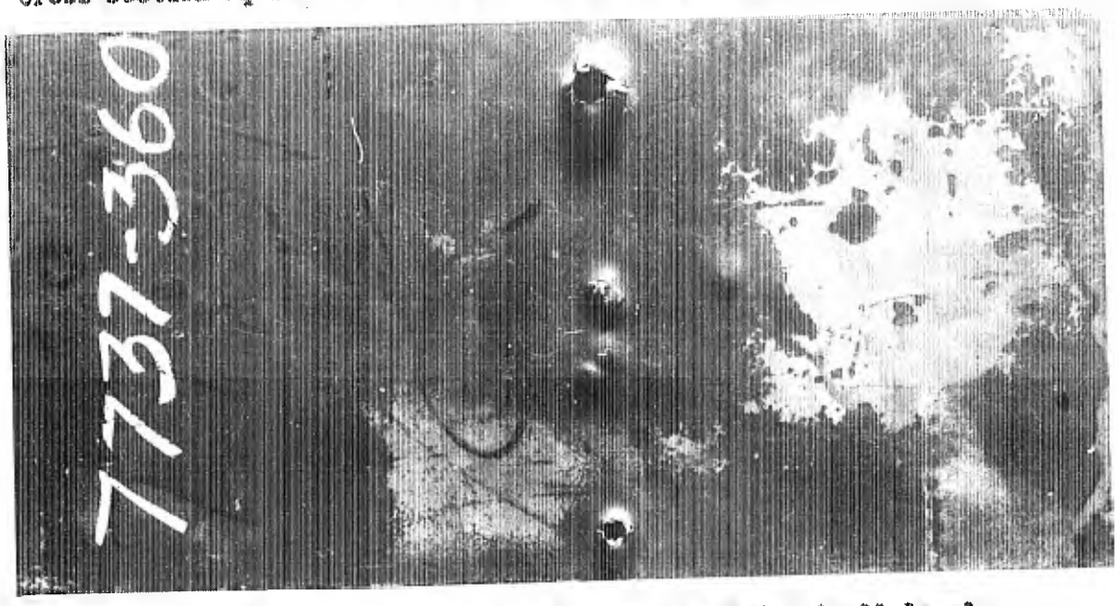
14677

Fig. 224. Same heat as shown above but at the 410 Brinell level. Cross-section equiv. Brinell hardness 426. Ballistic limit 2371 F/S.



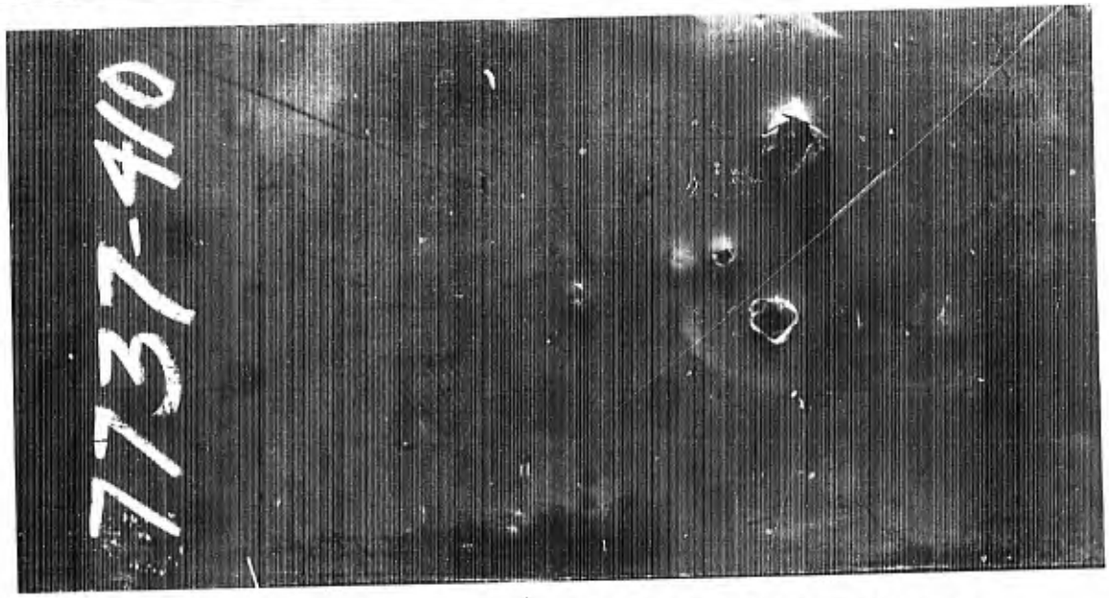
14594

Fig. 225. Heat No. 7737-320. Back of plate - photograph 1/2 actual size.
Cross-section equiv. Brinell hardness 327. Ballistic limit 2255 F/S.



14575

Fig. 226. Same heat as shown above but at the 360 Brinell level.
Cross-section equiv. Brinell hardness 372. Ballistic limit 2325 F/S.



14582

Fig. 227. Same heat as shown above but at the 410 Brinell level.
Cross-section equiv. Brinell hardness 409. Ballistic limit 2378 F/S.

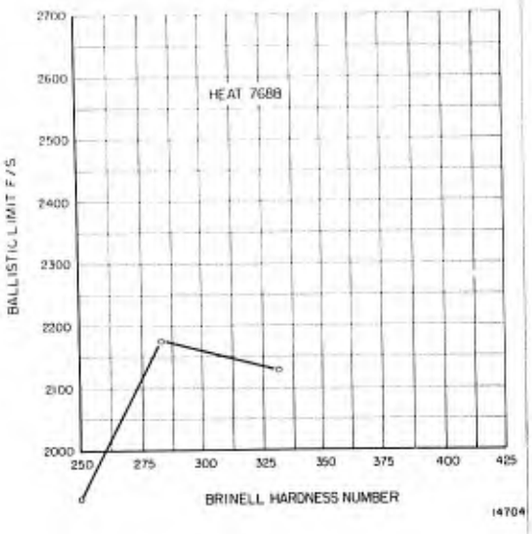


Fig. 228. Heat No. 7688.
Relationship of ballistic limit to Brinell hardness.

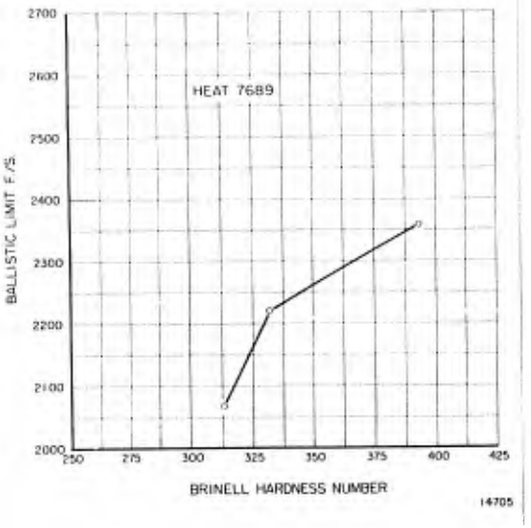


Fig. 229. Heat No. 7689.
Relationship of ballistic limit to Brinell hardness.

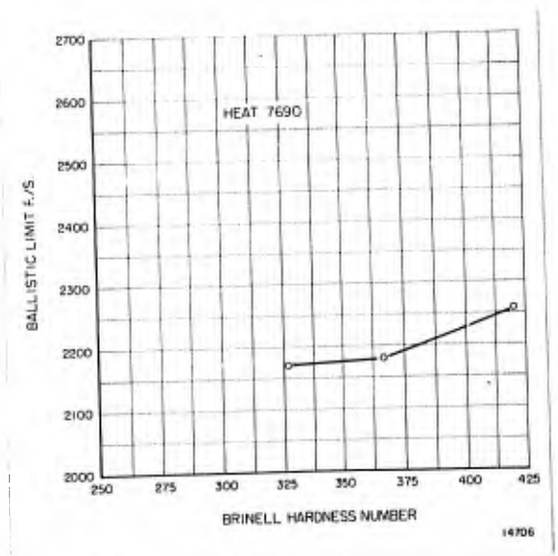


Fig. 230. Heat No. 7690.
Relationship of ballistic limit to Brinell hardness.

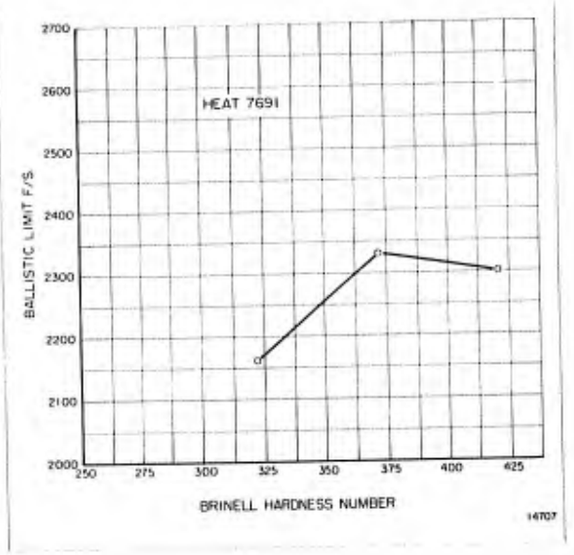


Fig. 231. Heat No. 7691.
Relationship of ballistic limit to Brinell hardness.

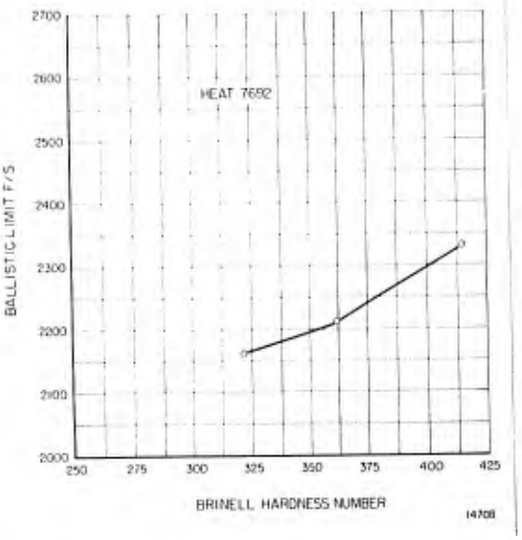


Fig. 232. Heat No. 7692.
Relationship of ballistic limit to
Brinell hardness.

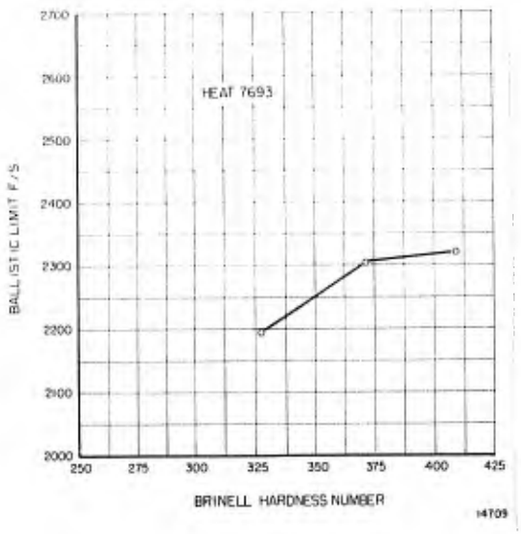


Fig. 233. Heat No. 7693.
Relationship of ballistic limit to
Brinell hardness.

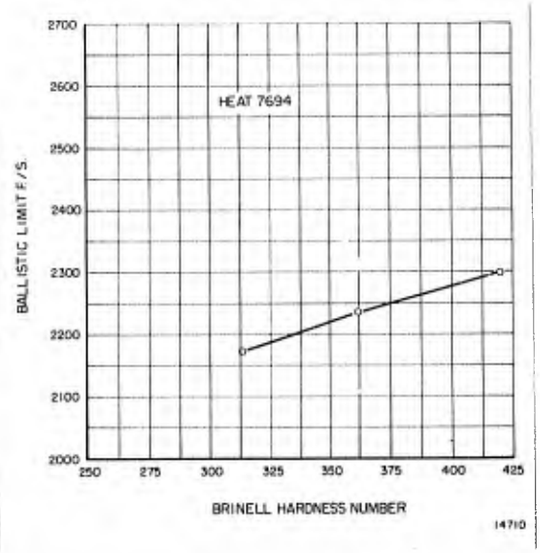


Fig. 234. Heat No. 7694.
Relationship of ballistic limit to
Brinell hardness.

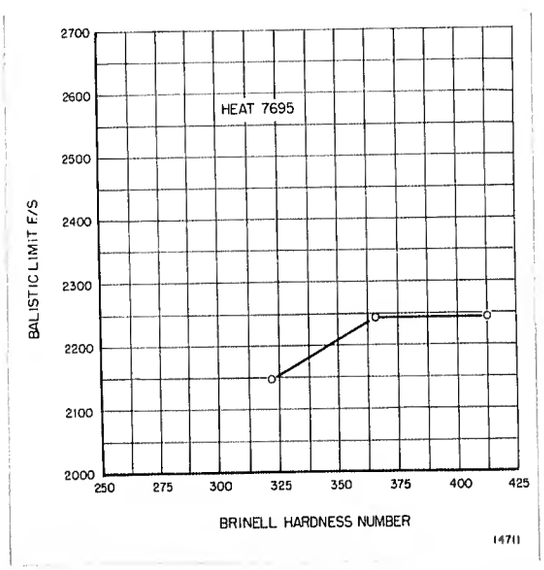


Fig. 235. Heat No. 7695.
Relationship of ballistic limit to
Brinell hardness.

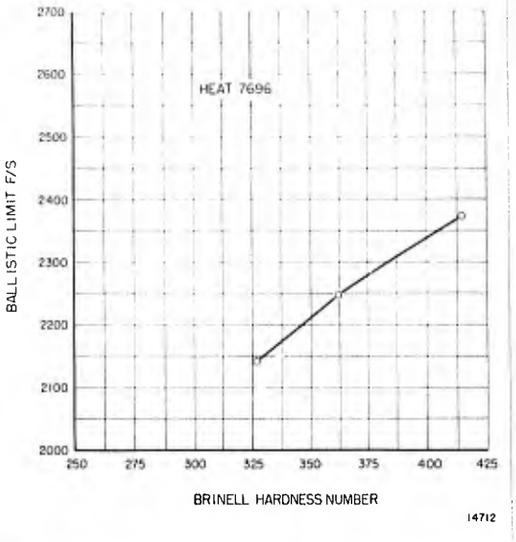


Fig. 236. Heat No. 7696.
Relationship of ballistic limit to Brinell hardness.

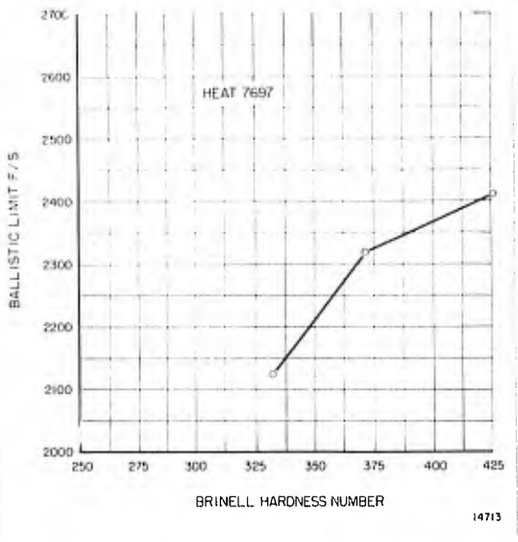


Fig. 237. Heat No. 7697.
Relationship of ballistic limit to Brinell hardness.

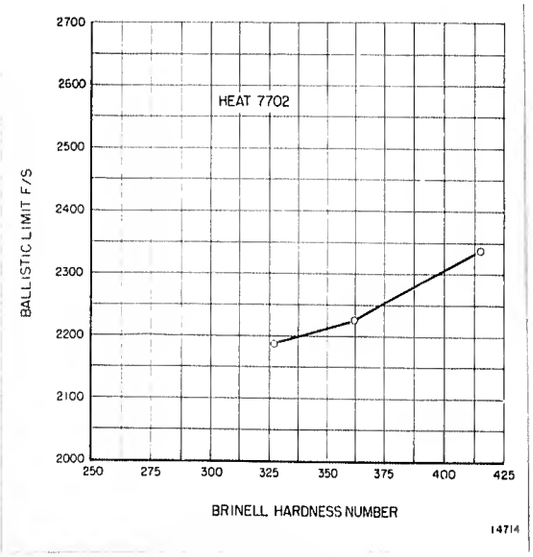


Fig. 238. Heat No. 7702.
Relationship of ballistic limit to Brinell hardness.

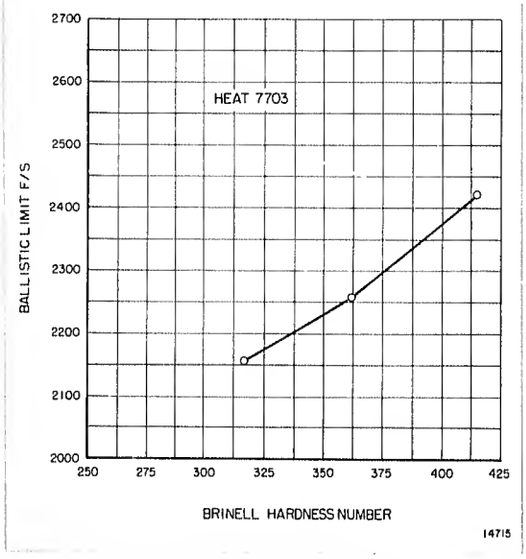


Fig. 239. Heat No. 7703.
Relationship of ballistic limit to Brinell hardness.

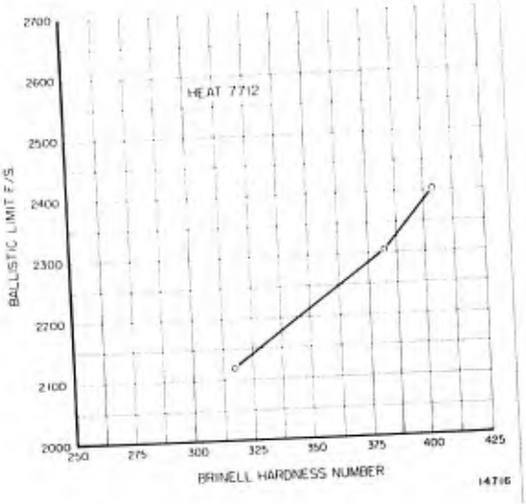


Fig. 240. Heat No. 7712.
Relationship of ballistic limit to Brinell hardness.

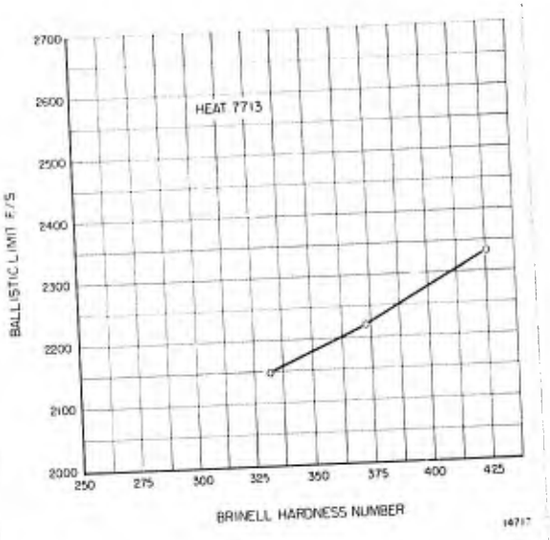


Fig. 241. Heat No. 7713.
Relationship of ballistic limit to Brinell hardness.

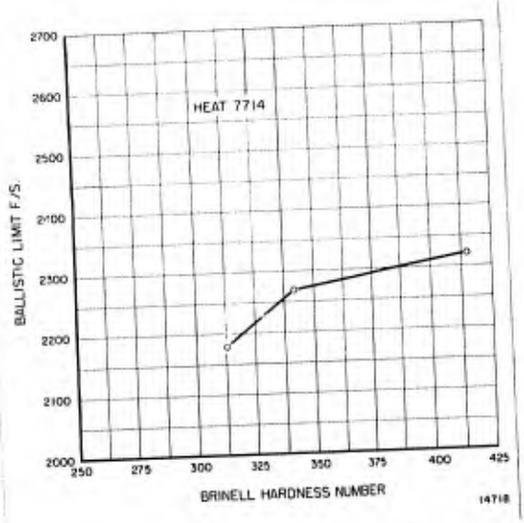


Fig. 242. Heat No. 7714.
Relationship of ballistic limit to Brinell hardness.

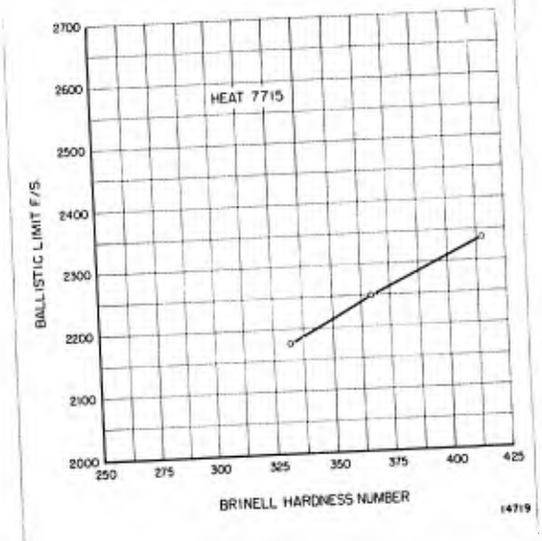


Fig. 243. Heat No. 7715.
Relationship of ballistic limit to Brinell hardness.

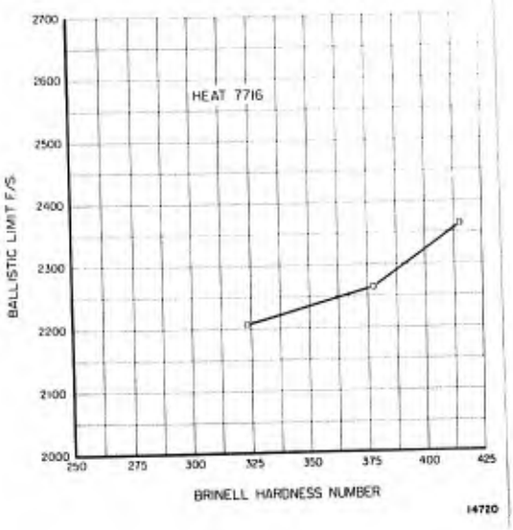


Fig. 244. Heat No. 7716.
Relationship of ballistic limit to Brinell hardness.

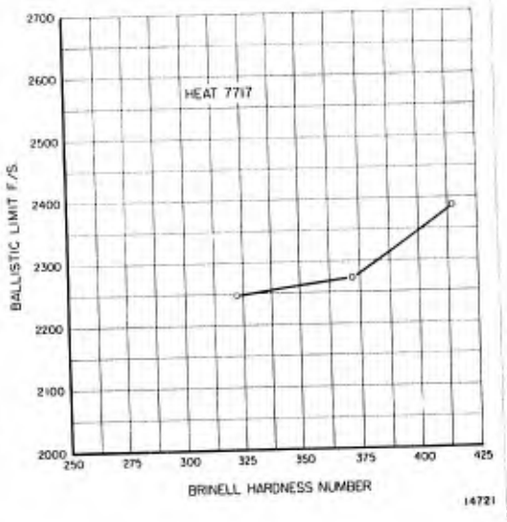


Fig. 245. Heat No. 7717.
Relationship of ballistic limit to Brinell hardness.

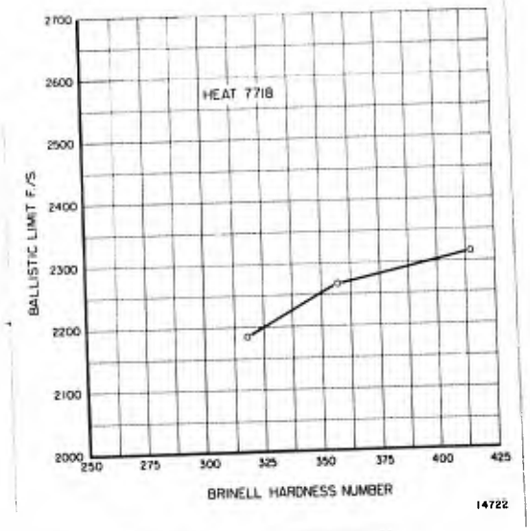


Fig. 246. Heat No. 7718.
Relationship of ballistic limit to Brinell hardness.

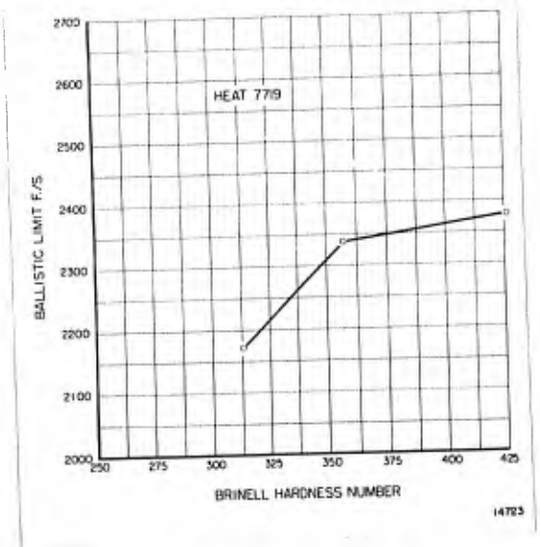


Fig. 247. Heat No. 7719.
Relationship of ballistic limit to Brinell hardness.

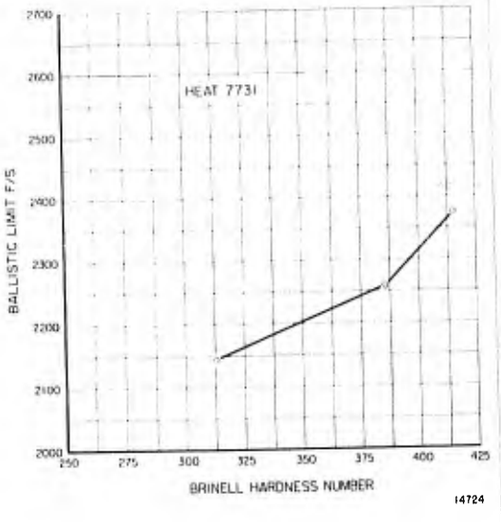


Fig. 248. Heat No. 7731.
Relationship of ballistic limit to Brinell hardness.

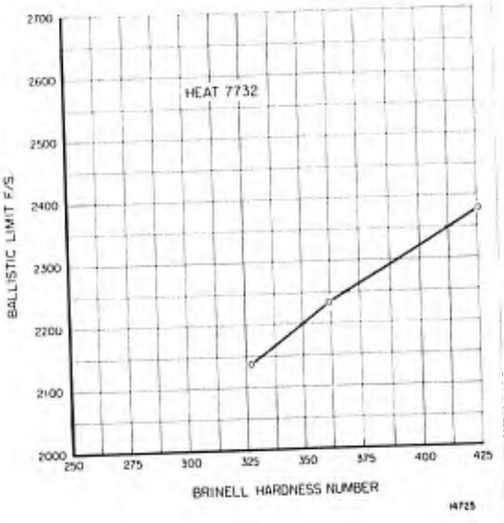


Fig. 249. Heat No. 7732.
Relationship of ballistic limit to Brinell hardness.

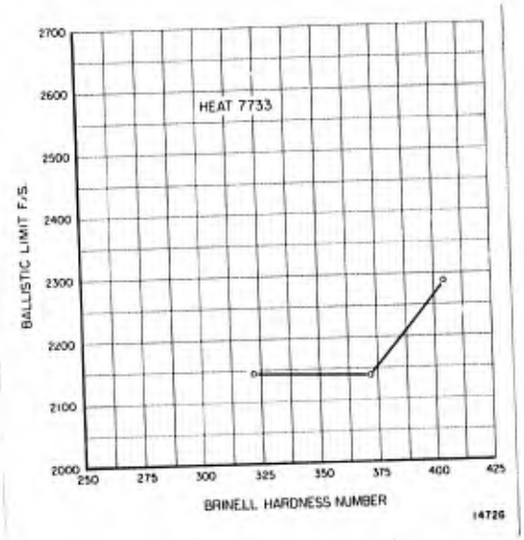


Fig. 250. Heat No. 7733.
Relationship of ballistic limit to Brinell hardness.

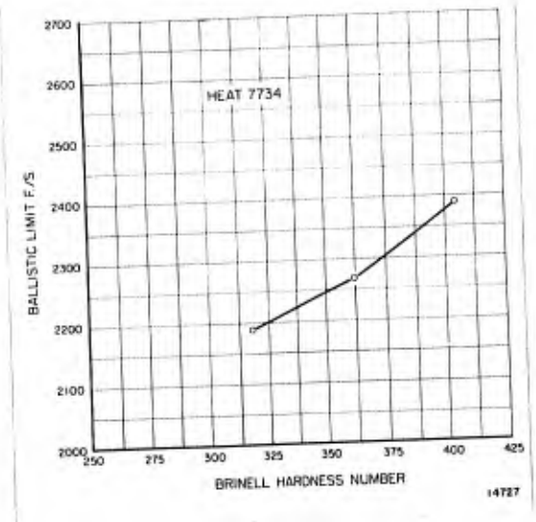


Fig. 251. Heat No. 7734.
Relationship of ballistic limit to Brinell hardness.

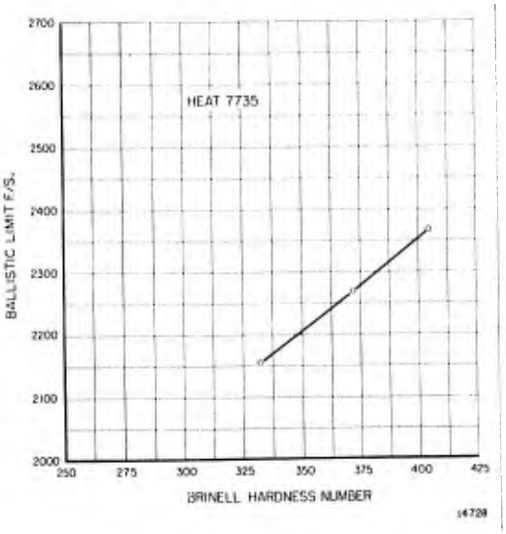


Fig. 252. Heat No. 7735.
Relationship of ballistic limit to
Brinell hardness.

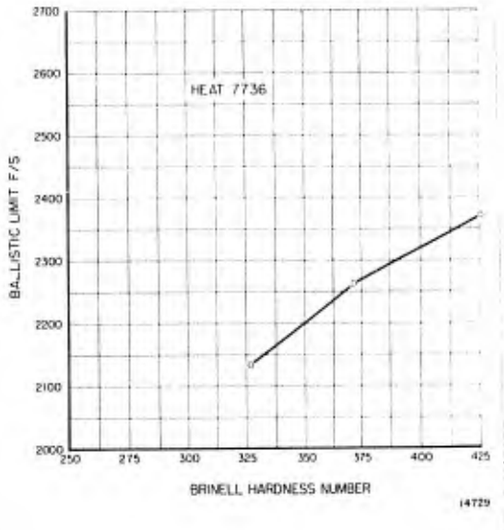


Fig. 253. Heat No. 7736.
Relationship of ballistic limit to
Brinell hardness.

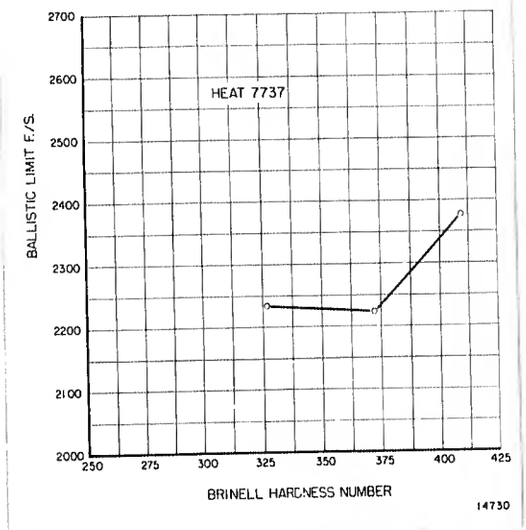


Fig. 254. Heat No. 7737.
Relationship of ballistic limit to
Brinell hardness.

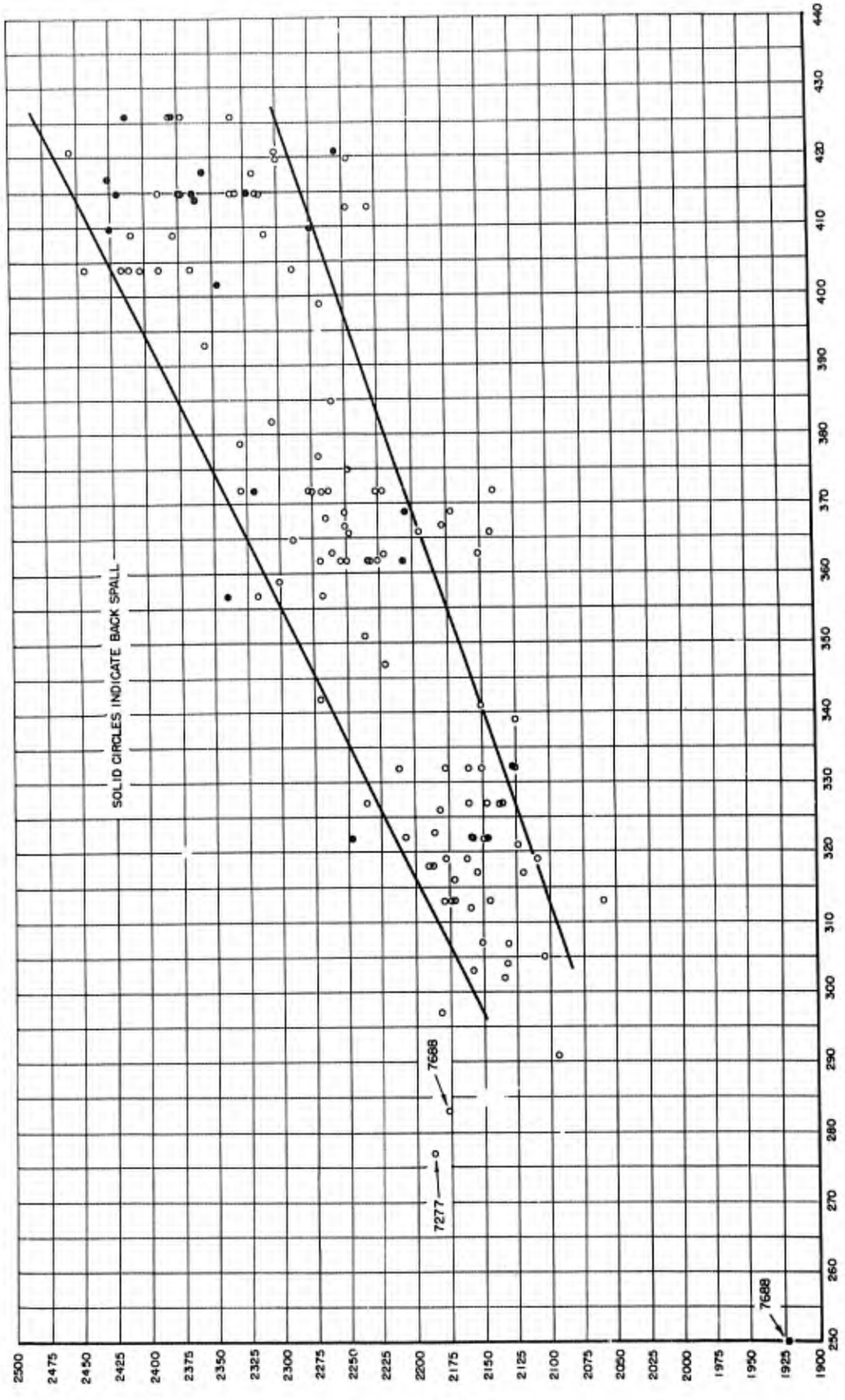


FIG 255-RELATIONSHIP BETWEEN BALLISTIC LIMIT AND BRINELL HARDNESS.