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Report No. 710/464
Watertown Arsenal
(Problem No. D-8)

November 3, 1942

FLAME CUTTING OF ARMOR

1" Rolled Homogeneous Armor (0.30% C)

OBJECT

To determine the maximum hardness developed by flame cutting armor plate of 0.30% carbon grade at room temperature, and to determine the preheat necessary to reduce this hardness to 400 Brinell.

CONCLUSIONS

1. The maximum hardness developed in flame affected area in armor plate of compositions investigated when flame cut at room temperature is approximately 500 Brinell.

2. A preheat of 400° F. is sufficient to limit this maximum hardness to 400 Brinell.

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INTRODUCTION

Armor plate of the 0.30% carbon grade has shown a tendency toward excessive hardening and cracking at edges flame cut without preheating. It was, therefore, suggested by members of the Subcommittee for Welding of Armor that a few tests be made at this arsenal to determine the extent of preheating necessary to minimize the tendency toward cracking. The opinion of members of the Subcommittee was that flame cut edges with a maximum hardness of 400 Brinell would not crack.

TEST PROCEDURE

One inch thick plates of armor with the desired carbon content which had been submitted to the Armor Section of the Laboratory for ballistic testing were obtained after completion of ballistic tests. Preliminary experiments indicated that the following flame cutting conditions gave a cut similar to those obtained in commercial practice and these conditions were observed in all tests.

Travel speed	14 inches per minute
Oxygen pressure	60 lbs. per sq. in.
Type of torch	No. 2 Harris tip

Four flame cuts were made at room temperature, and 200°, 400°, and 600° F. preheats, respectively in a 6" x 12" plate, made by the Great Lakes Steel Coproration. Specimens were taken at the flame cut edge and surveyed for hardness. The 400° preheat appeared adequate in these tests. To check this an 18 inch cut was then made at 400° preheat in the long leg of an H plate which had been welded from armor plate, made by Simonds Saw and Steel Company. The hardness in 30° bevel cuts was then determined by making two 9 inch cuts, one at room temperature and the other at 400° preheat, in the other leg of the H plate. Location of all flame cuts and of hardness specimens is shown in Figure 1.

Preheating was carried out by heating the small specimens to 50° over the preheat temperature in a small heat-treating furnace, then allowing them to cool in air to the proper temperature before making the flame cut. Preheating for the 9 and 18 inch cuts was carried out with a gas torch. Plate in the region where the cut was to be made was heated to about 50° above the desired preheat temperature and flame cut was made after this area had cooled to proper temperature.

All final operating temperatures were determined by the use of Tempils.

Hardness surveys, macro- and microexaminations were then carried out as detailed below.

DATA AND DISCUSSION

1. Chemical Analyses

Results of chemical analyses were as follows:

6" x 12" plate (Great Lakes): .32% C, .82% Mn, .71% Si, .035% S, .036% P, .73% Cr, .21% Mo, .09% Zr.

18" x 18" H plate (Simonds Saw and Steel): .33% C, 1.55% Mn, .18% Si, .016% S, .020% P, .06% Cr, .25% Mo.

Provided that a quench is sufficiently severe to produce martensite, maximum hardness is largely a function of carbon content for a given heating and cooling cycle, as opposed to depth of hardening (hardenability) which is greatly influenced by added alloy. Hence, the difference in added alloys to these plates will not have a large effect on the maximum hardness observed in the flame cut edges, so long as the carbon contents are comparable.

2. Hardness Surveys

Vickers Brinell hardness surveys were made on seven specimens taken from plates as indicated in Figure 1. Locations of Vickers Brinell impressions and tabulation of hardness readings are given in Figures 2 and 3. The first four specimens were from cuts made in identical manner except for preheat. Maximum hardnesses of 536 Vickers Brinell at room temperature, 498 at 200° F. preheat, 429 at 400° F. preheat, and 348 at 600° F. preheat were observed. Maximum plate hardness is 330 Vickers Brinell; thus the hardness of 429 Vickers (approximately 397 standard Brinell) in plate preheated to 400° F. does not appear excessive.

Specimens 5 through 7 were taken at beginning, middle, and end of 18 inch cut. Maximum observed hardness was in specimen taken from end of cut and was approximately equal to 400 standard Brinell.

Specimens 8 and 9 were taken from middle of two 30° bevel flame cuts. A maximum hardness of 542 Vickers Brinell (approximately 494 standard Brinell) was observed in specimen from cut made at room temperature, and a maximum of 366 Vickers Brinell (approximately 340 standard Brinell) was observed in specimen from cut made with 400° F. preheat.

3. Macroexamination

Figure 4 shows a photomacrograph of specimen No. 2 after hardness survey and light etch with 1% nital. The thickness of the heat affected zone tapers from 3/16 inch at top of plate to 1/16 inch at bottom. This is typical of most of the flame cut specimens. However, the specimen taken at the beginning of the 18 inch flame cut showed a much wider heat affected zone where flame was held for a few seconds to start cut. In this case the flame affected area was softened rather than hardened.

4. Microexamination

A very narrow dark band was observed along flame cut edge in hardened zone of macroetched specimens. This band was examined at 250 magnification, Figure 4, and found to consist of ferrite, troostite, and some pearlite, indicating that the edge had been decarburized sufficiently to prevent full hardening. Immediately beyond the decarburized edge is the martensitic flame hardened zone, extending as far as the plate metal has been heated above the lower critical temperature (approximately 1330° F.). Beyond the hardened zone is a softened zone where the heat of flame cutting has tempered the hardness of the original plate.

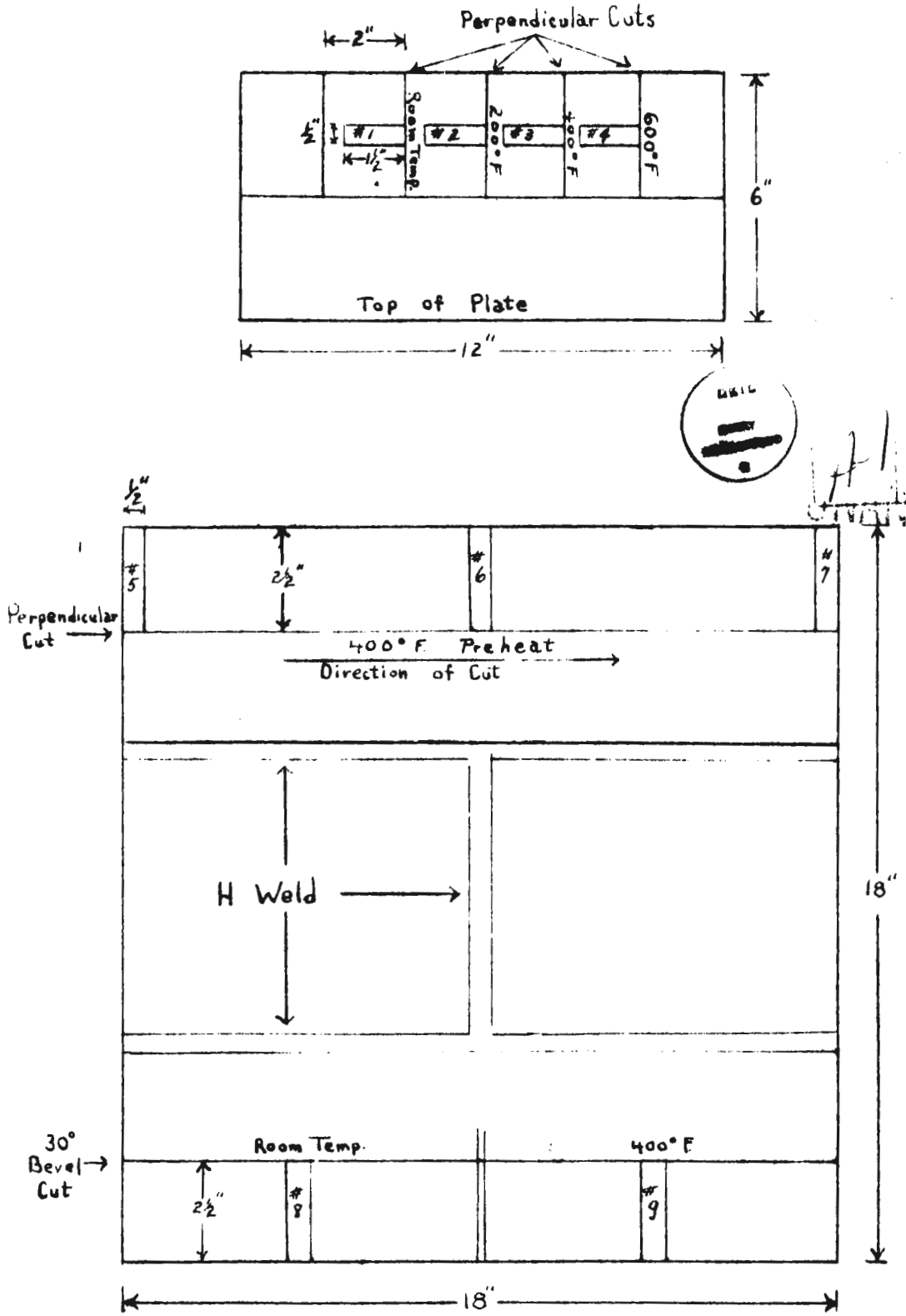
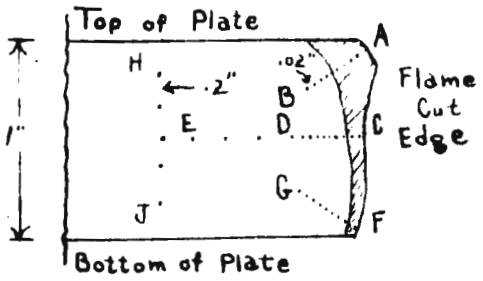


FIGURE 1. LOCATION OF HARDNESS SPECIMENS



LOCATION OF VICKERS BRINELL IMPRESSIONS

Three Inch Cut (Great Lakes).

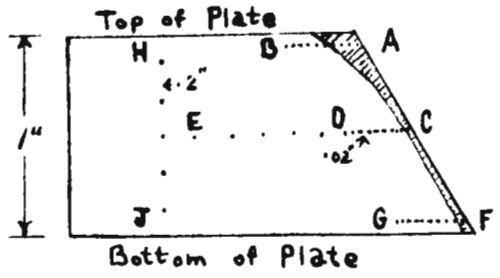
Specimen	1					2					3					4				
Preheat	Room Temp.					200° F					400° F					600° F				
AB	CD	DE	FG	HJ	AB	CD	DE	FG	HJ	AB	CD	DE	FG	HJ	AB	CD	DE	FG	HJ
429	519	322	363	322	478	429	306	345	330	385	370	312	302	327	325	327	312	312	325
437	514	330	390	330	498	408	297	359	304	425	385	306	302	309	345	322	314	306	312
387	536	330	339	330	498	287	292	314	304	417	350	304	304	312	348	285	314	299	322
304	508		292	330	488	283		327	304	429	289		299	314	348	258		297	314
312	450		314	322	433	294		333	330	421	283		317	307	339	276		314	325
325	387		322		380	294		339		376	302		319		322	294		325	
325	306		322		354	304		339		348	312		319		312	306		330	
325	304		322		325	309		339		339	322		319		306	312		336	
319	319		322		302	309		342		304	322		319		297	317		327	
319	322		322		309	309		336		287	322		317		268	317		330	

Eighteen Inch Cut (Simonds Saw and Steel)

Specimen	5					6					7				
	Start of Flame Cut					Center of Flame Cut					End of Flame Cut				
	AB	CD	DE	FG	HJ	AB	CD	DE	FG	HJ	AB	CD	DE	FG	HJ
	304	304	317	272	325	351	397	304	360	306	397	380	272	365	276
Preheat	312	309	314	289	322	366	317	287	322	297	455	336	276	351	266
	312	297	314	289	319	360	304	281	312	287	394	302	279	336	274
400° F	294	292		289	314	306	274		304	289	376	274		327	274
	294	297		292	314	319	285		287	299	348	270		299	285
	312	302		304		319	274		294		330	268		299	
	302	294		289		302	270		294		309	276		302	
	292	289		289		309	272		292		302	268		306	
	281	289		289		281	285		302		302	266		314	
	289	285		297		270	287		299		306	266		299	

FIGURE 2. VICKERS BRINELL HARDNESSES
STRAIGHT CUT

(See Fig. 1 for Specimen Location)



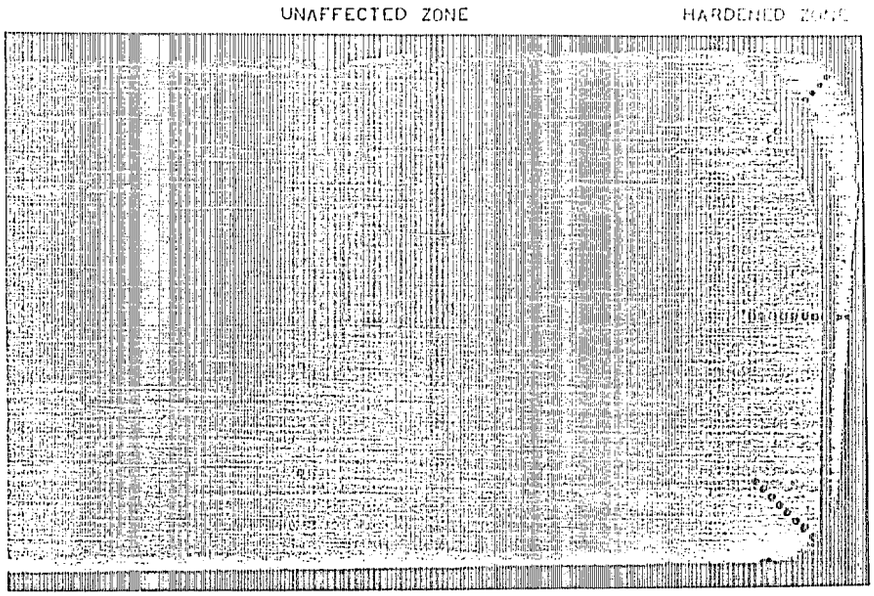
LOCATION OF VICKERS BRINELL IMPRESSIONS

Nine Inch Cut (Simonds Saw and Steel)

Specimen	8				9				
Preheat	Room Temp.				400° F				
AB	CD	DE	FG	HJ	AB	CD	DE	FG	HJ
556	566	514	459	279	527	536	276	514	297
542	580	509	514	292	566	512	287	517	299
536	287	514	590	294	554	502	274	504	287
542	512	514	560	309	527	274	276	297	292
525	512	514	522	299	556	282	279	294	289
514	509		294		559	282		279	
455	514		504		519	270		276	
405	517		512		304	279		294	
287	514		504		294	276		292	
506	514		506		294	285		292	

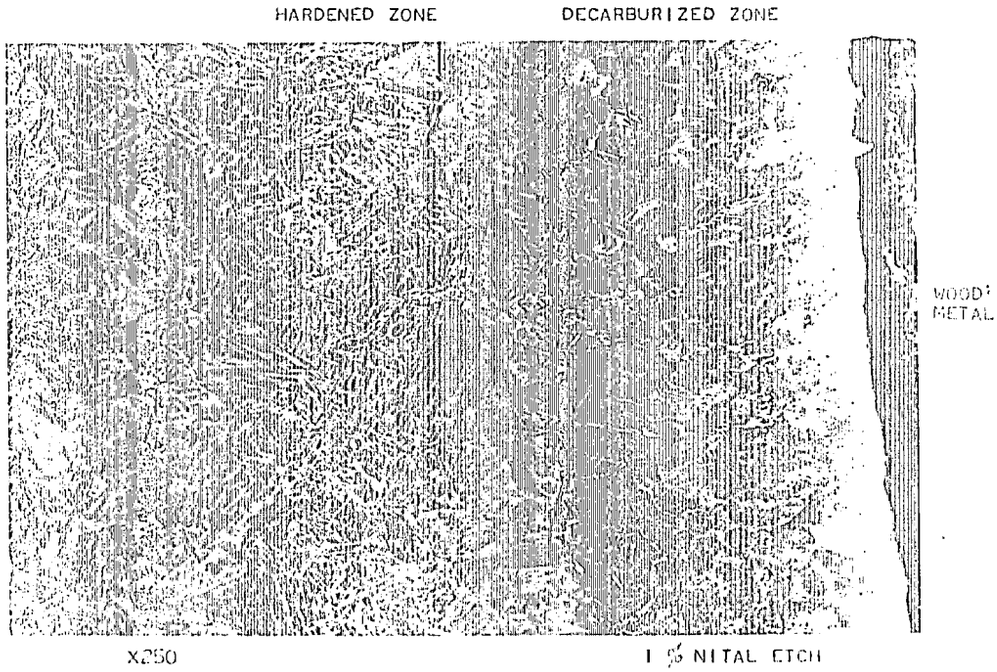
FIGURE 5. VICKERS BRINELL HARDNESSES
50° BEVEL CUT

(See Fig. 1 for Specimen Location)



X3 1 % NITAL ETCH

CROSS SECTION SHOWING EXTENT OF HARDENED ZONE AND LOCATION OF HARDNESS IMPRESSIONS.



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X250 1 % NITAL ETCH

DECARBURIZED ZONE AT FLAME CUT SURFACE.

FIGURE 4