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Technical Note: Application of SWAT to the Nondestructive Inspection of Welds

BY C. E. HARTBOWER

SWAT is an acronym for Stress Wave Analysis Technique. Stress waves are produced by the release of elastic energy resulting from the growth of a crack in a stress field. Thus, SWAT constitutes a unique nondestructive inspection method in that the material defect, when propagating, transmits its own signal, with the sensor acting as the receiver. In other words, the material undergoing crack growth both generates and transmits the signal. The SWAT system, consisting of sensors, amplifiers and filters (to eliminate extraneous low-frequency noise) serves as the receiver. System sensitivity can be preset to trigger on a selected signal amplitude, and the operational and reliability status of the system can be checked by periodically inserting a calibration signal. The utility of SWAT as a new, highly sensitive method for monitoring crack growth has been demonstrated in several researches.[1-7]

The objective of the experiment described here was to demonstrate the feasibility of SWAT as a method for obtaining data on delayed weld cracking. In the fabrication of HY-80 submarine hulls, a minimum period of seven days is allowed before nondestructive inspection to be certain that any delayed cracking that might occur will have been completed. Obviously, if a quantitative measurement can be made of the time involved in the delayed cracking process, it may be possible to shorten the minimum time between completing a weld and nondestructive inspection and, thereby, save submarine production time.

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The Test Weldment

HY-80 steel (MIL-S-16216-G) in the form of 2-in.-wide by 10 in. long by 0.70 in. thick bars were welded to form a test plate 8 in. wide by 10 in. long. Thus, there were three longitudinal welds 10 in. long joining four 2 in. wide bars. The joint design was simply a square butt; incomplete penetration was deliberate to assure cracking. The welding was done by the tungsten-arc process using a 600 amp, automatic welding unit and Linde-83, 1/16 in. diameter filler metal conforming to AWS-ASTM classification E-70S-G.

The welding sequence is shown in Fig. 1; note that two weldments 4 in. wide by 10 in. long were prepared first, and then joined to make the 8 in. wide x 10 in. long test weldment. Passes 1-4 and 9-10 were fusion passes (without filler metal); passes 5-13 involved filler metal automatically fed into the arc at 20 kw. The arc travel speed was 6 ipm at 350 amp and 10 v. The interpass temperature was not controlled; however, the time between passes was recorded, indicating the interpress temperature to be between 300 and 500° F. Contact-pyrometer readings taken after the final pass showed the weldment to be about 225° F at the time the SWAT system was activated.

The SWAT System

The weldment was placed in a sound-insulated chamber at 4:30

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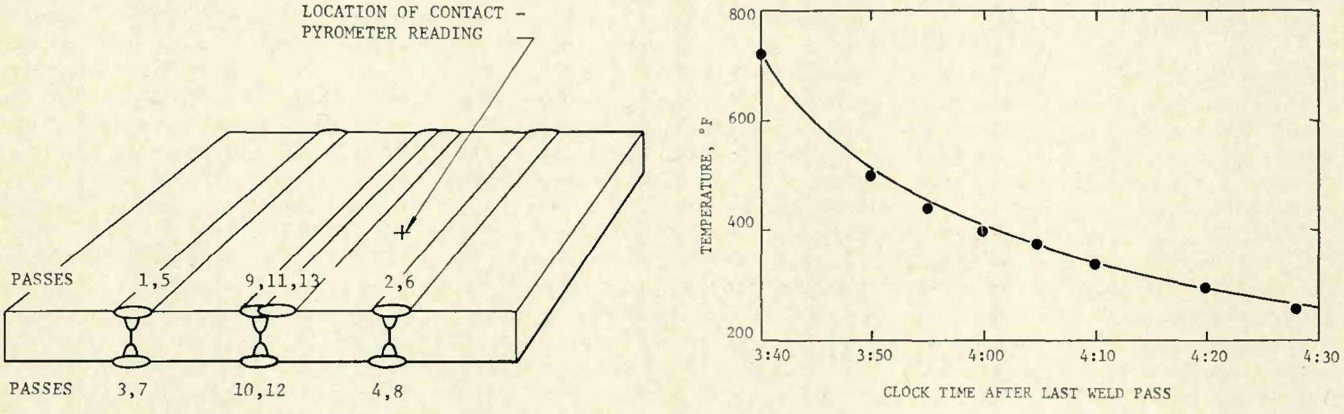

Fig. 1—Weld sequence and temperature

Shuler for doing the welding and much of the associated laboratory work. Thanks are also due to Mr. J. Lynch who helped with the statistical analysis of the data.

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P.M.; the SWAT system was activated at 4:41 P.M. Figure 2 is a schematic of the system. With 100X amplification follwed by a 30 kc high-pass filter and then 1000X amplification, a 38 kc input signal (approximately resonance frequency of mounted accelerometer) is amplified 5000X.

In the counter system, two levels of stress-wave amplitude were recorded. The counter stripchart printout recorded cumulative count and count rate (number/minute). By a voltage setting, the count-rate printout was adjusted to read signals just above the background noise level. The cumulative count was set to record the larger stress waves, approximately 5X those of the count-rate printout.

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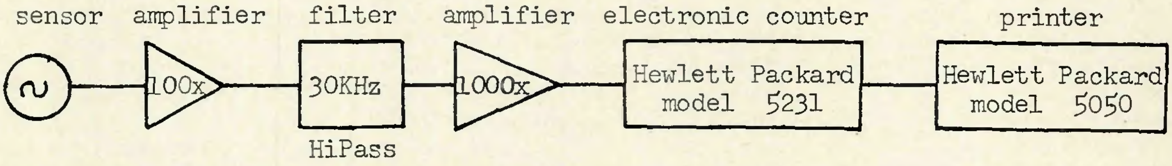

Fig. 2—Schematic representation of the SWAT system

Table 1—Delayed Cracking in Welded HY-80 Steel

Date	Time of Signal Clock time	Stress-wave emission Cumulative count[a]	Stress-wave emission Count per minute[b]
3 Apr '69	02:25 PM	(Started welding)	
	03:40	(Welding completed)	
	04:40	(Started counter)	
	49	0	5
	50		10
	51	2	437
	52		6
	56		1
	58	16	925
	05:04		3
	07	978	2239
	10		28
	14		27
	15		4
	16		
	19		20
	21		17
	23		40
	24		11
	26		3
	29	2372	4550
	30		8
	31	3492	3912
	33	4322	2975
	34		17
	35	4567	1146
	37	5539	3751
	38		27
	39	5932	1324
	40	5955	116
	42		33
	46		18
	48		47
	52	5955	
	53	6346	1581
	58		38
	06:00		20
	02		2
	04	6998	2166
	05	7008	1225
	07		13
	08	7030	123
	09		8
	20		10
	29		2
	31		2
	33	7036	35
	34	7039	16
	37		8
	55		1
	07:09	7040	22
	21	7078	125
	22		89
	08:11		2
	24		1
	09:01		1
	59		44
	10:45		76
	11:48		129
4 Apr '69	00:23 AM		90
	24		8
	37	7082	518
	45		49
	01:03		164
	03:03		75
	04	7107	176
	07:41		446
	06:53 PM		18
5 Apr '69	00:15 AM		25
	07:19 PM		1
	20	7108[c]	37
6 Apr '69	—	—	—
7 Apr '69	07:30 AM	System off	

[a] Counter triggered at 1.0 volt.
[b] Triggered at 0.25 volt.
[c] Corrected to eliminate system check-out signals.

length and tip position will be found to be vital to a programmed penetration control system.

Some of the considerations may point the way toward improved parameter combinations in pulsed gas tungsten-arc welding, where electrode heating, when it is the prime source of directed heat, does not rise instantaneously but lags the current pulse.

It is clear that generalities about electrode or arc behaviors cannot be made without identification of the electrode shape and background resistances. Transferability of weld parameters from machine to machine in a plant or between plants for a given job has met with problems and scattered results. This has been discouraging since a volt or an ampere should be a fixed quantity anywhere. The position of the instrumentation taps, the resistance drops in the power loop between the instrumentation taps, and the reaction of the resistance to current and time are vital standards for this purpose. The work completed herein has been exploratory. The accuracy of absolute numbers could not be a prime goal of this study. However, the examples, the comparisons, the several cause and effect trends are expected to survive the results of carefully controlled specialized experiments. Some of what is conjecture or spuculation can be measured by specific tests.

The influence of electrode shape on the cathode emmission surface, the arc and the anode, surface is so significant that those experiments which have failed to specify electrode shape, the length to holder, the cold and hot resistance, or the time of data taking, can only report varieties of trends. In some experiments the failure to recognize resistive heating of the cathode has confounded conclusions. Yet it may be of advantage to the serious scientist to exploit the difference in electrode shapes to isolate the behavior of those sub-systems that ate of so much interest to physicists and welding researches, or to exploit the difference in results given from a cold electrode or a hot electrode, or the resistance rise-rate of various electrode systems.

The resistive components that react negatively to current increase, give a function which drops to a level at 200 amp and is nearly constant through higher currents. The difference in levels for different electrodes and the sublte tendencies with increasing current may contain clues that expose more laws governing cathode emission or the arc.

The resistive components which rise with current give a function r_t which rises at a constant rate with current. The finer electrodes start and remain higher than the blunter. Each of these functions may be further analyzed and tested for their representation of real sites of physical events and for their own several components that tell separate stories.

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Test Results

Table 1 lists the stress waves that were recorded over a period of approximately 87 hr of continuous monitoring. Note that count rate (highest sensitivity seting) recorded the first burst of stress waves 9 minutes after activating the counter system. Note also that the greatest stress-wave activity occurred in the first seven hours (cumulative count of 7078). In the next 24-hour period, the cumulative count increased by only 29, and in the following 24-hour period, the cumulative count increased by only 1. There were no stress waves recorded in the 3rd 24-hr period. Thus, for all practical purposes, the cracking occurred in the first 24 hr after welding was completed.

Discussion of Results

The weldment for this test was designed to crack. The square butt joint involved incomplete penetration, and the initial fusion passes were small and cracked before the filler passes were deposited. Thus, the cracking that occurred during welding may have resulted in some degree of stress relief and thereby shortened the period of delayed cracking. Therefore, a quantitative measurement of the duration of delayed cracking will require monitoring restrained joints that are representative of shipyard practice and free of hot cracking.

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