HA-2209

Progress Report No.9

DEVELOPMENT OF CONTROLS FOR TIME-TEMPERATURE CHARACTERISTICS IN ALUMINUM WELDMENTS

CONTRACT NO. NAS8-11930
Control No. DCN1-5-30-12723-01

Covering Period
December 1, 1965 thru December 31, 1965

Prepared For
George C. Marshall Space Flight Center
National Aeronautics and Space Administration
Huntsville, Alabama

January 10, 1965

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ABSTRACT

This report contains a summary of accomplishments during the first nine months of a two-phase research program to develop methods, tooling concepts, and processes to control the time-temperature characteristics in the weld and heat affected zone, in order to improve tensile properties and reduce porosity in aluminum weldments.

The results of the first phase, which consisted of a survey of literature and industry, were reported in August 1965 (HA-2174). Equipment has been modified, with instrumentation installed to monitor welding variables. An evaluation of infrared radiometers for application to the program is in progress, and some favorable results are indicated. Tentative thermal patterns for comparison of chilled and unchilled weldments have been obtained. These patterns show that chilling with liquid CO_2 substantially increases the cooling rate of weldments in both 5/16" and 1/2" 2014-T6 plate. Macrosections show reduced width of heat affected zone and smaller grain size for chilled weldments. Preliminary results of X-ray examination and tensile tests indicate that chilling with liquid CO_2 reduces porosity and improves tensile properties. Work on modification of equipment and refinement of techniques for producing and controlling optimum thermal patterns is in progress.

I. ACCOMPLISHMENTS PREVIOUSLY REPORTED

A. Summary

During the four month period of Phase I, sixty-three reports of previous work in related fields were reviewed, and seventeen industrial and governmental organizations were contacted. By combining the pertinent information from this survey with the original technical concept, a program plan was developed for the experimental work to be performed in Phase II. Materials have been procured and preliminary modification of equipment has been completed. Experimental work has been initiated, with preparation of reference weldments and preliminary studies using liquid CO_2 for chilling. Tentative data have been obtained for thermal patterns, tensile properties and porosity content of chilled and unchilled welds in 2014-T6 plate.

B. Literature Reviewed

The purpose of the survey was to obtain information which might be helpful in the performance of this program, by avoiding duplication of effort and/or by supplementing the original program concept.

Current abstract bulletins published by the National Aeronautics and Space Administration (STAR) and by the Defense Documentation Center (TAB) were checked for reports of work pertinent to fusion welding of aluminum, and significant reports were acquired for review.

A similar survey was made of applicable technical books and periodicals, including those of the American Welding Society, the American Society for Metals, and the American Institute of Mining and Metallurgical Engineers. Particular emphasis was devoted to issues of the Welding Journal published during the past ten years.

Sixty-three reports were selected for review and were classified under three general subject areas according to their principal interest to this program: (1) Time-Temperature Studies, (2) Heat Flow During Welding, and (3) General Welding Techniques.

No reported or unreported work was found which would indicate that any part of this program is a duplication of effort. A considerable amount of information was obtained which will facilitate the experimental portion of the program, particularly that work pertaining to heat transfer analysis and specific welding techniques currently in use for fabricating aerospace structures by welding the particular materials involved.

C. Organizations Contacted

Those organizations and individuals who were considered to be involved in work related to this program were contacted for personal interview or for interview by telephone. The cooperation was excellent, and in some cases special data were furnished and tours of plant facilities arranged. In general, a great deal of interest was expressed in this program.

It appears that at the present time, no specific work is in progress to develop data in addition to that already reported in the literature for development of time-temperature controls or theoretical heat flow information for welding of aluminum alloys.

However, in some work recently completed by Frankford Arsenal it was determined that three significant trends were noted in the microstructure which indicate the merit of the use of super-chilling during welding of aluminum:

(1) the amount of micro-porosity was substantially lessened,
(2) the width of the zone of grain boundary melting at the interface was reduced appreciably, and
(3) a finer grained cast structure was obtained.

All of this work was performed on 0.090" thick 2014 and 2024 aluminum alloys. In one set of experiments the chill bars (both top and bottom) were cooled with brine at -45°F.

In a second set, for which data has just been published, the chill bars were cooled with liquid nitrogen. In each case, welding was performed after the parts to be welded reached a selected temperature, $-30^{o}F$ and $250^{o}F$, respectively. Difficulty with condensation of moisture on the parts was overcome by enclosing the part in a flexible plastic bag containing dry argon or helium.

A large amount of work has been done and is currently in progress to improve the quality of weldments in aerospace components fabricated from aluminum. Although only a few specific studies have apparently been conducted on a laboratory basis for determining the effect of time-temperature on properties of weldments, a good many of the process controls adopted for shop welding are aimed in the direction of controlling thermal patterns.

D. Experimental Program

1. General

The experimental program will consist of two essential steps. The first will be to establish realistic target thermal patterns designed to improve the weld properties, and the second will be to devise and test various means of providing the time-temperature controls required to attain the optimum thermal patterns for welding the plate in two thicknesses, 1/2" and 5/16", in each of two alloys, 2014-T6 and 2219-T87. Welding will be performed in the horizontal position by the semi-automatic TIG process, using direct current straight polarity, on square butt joint preparation, with 2319 filler wire and helium shielding gas. It is contemplated that cryogenic liquids and auxiliary heat sources will be used to alter thermal patterns during welding. Tensile tests and hardness surveys will be used to correlate mechanical properties with thermal patterns.

2. Modification of Equipment

Existing equipment was modified for welding test panels from one side in the horizontal position. The basic equipment consists of a Miller Model 600/1200 power supply, a Miller high frequency unit, a Berkeley Davis side beam and carriage system, an Airco TIG welding torch and wire feed system with mounting brackets, a fixture for 12" x 48" weld panels, a cryogenic jet spray system, and suitable brackets and attachments for mounting radiometers.

3. Instrumentation

The instrumentation for monitoring welding process variables and thermal patterns in the weld panels consists of a Weston ammeter and a voltmeter, an optical tachometer, a Leeds & Northrup 12-channel temperature recorder with thermocouples, an Airco helium flowmeter, an Airco filler wire speed regulator, and a Tektronic oscilloscope.

Additional instrumentation being evaluated on a loan basis includes fixed point infrared radiometers, a Barnes scanning infrared radiometer, and a Honeywell Visicorder.

4. Reference Weldments

In order to establish reference data to which future experimental welding will be compared, weldments in each of the aluminum plate materials were fabricated under monitored conditions without the use of chilling. The thermal pattern data in connection with the mechanical and metallurgical characteristics of these weldments will be used as the starting point for alteration of thermal patterns to improve the properties.

Weldments of satisfactory physical appearance were produced in 5/16" thick and 1/2" thick 2014-T6 plate using the following welding parameters for the penetration pass:

Thickness	Amps.	Volts	Weld Travel
5/16"	250	14	9.0 ipm
1/2"	300	16	6.5 ipm

5. Preliminary Check-out of Cryogenic System

Preliminary trials of the liquid CO_2 system indicated that more than adequate chilling effects can be obtained on the back side of the weld. A 250 lb. container with flexible delivery tube and a variety of nozzles with orifice sizes from 0.008" to 0.032" have been received.

6. Preliminary Experimental Results Using Liquid CO_2 Chilling

a. Time-Temperature Studies

Tentative thermal patterns have been plotted from data obtained during preliminary experimental work to determine the effect of chilling with liquid CO_2. Substantial changes were noted for welds in both the 5/16" and 1/2" 2014-T6 plate. The total time at temperatures above 500°F was reduced over 25% by chilling. The quench rate from 750 to 500°F was more than doubled for 5/16" welds and increased almost 40% for the 1/2" welds.

b. Metallurgical Studies

Macrosections of weldments indicated a narrower heat affected zone and reduced grain size for chilled weldments.

c. X-ray and Fracture Studies

Results of preliminary X-ray examination and tensile test and fracture studies indicate that chilling the back side of the weld with liquid CO_2 effects some reduction in gross porosity. For welds in 5/16" 2014-T6 plate, the average porosity for all specimens from the unchilled weld panel was 5%, while the average porosity for all specimens from the chilled weld panel was 2%, indicating that chilling reduced the amount of this porosity by a factor of more than two. For specimens from the 1/2" plates, welded without the addition of filler, X-ray results and fracture studies indicated less than 1% porosity in both chilled and unchilled welds.

Gross lineal porosity appears to be associated with the addition of filler wire. The causes for fine scattered porosity have not yet been determined. In both instances, the causes must be investigated and corrected before the effect of chilling on eliminating or reducing porosity and improving weld properties can be properly evaluated.

While these results cannot be considered conclusive, and indicate the need for further refinement of general welding techniques, there appears to be sufficient evidence of improvement to warrant further development of the current concept.

d. Tensile Tests

The following table shows averages of tensile test results for specimens from welded panels in 5/16" and 1/2" 2014-T6 plate:

Comparison of Tensile Properties of Unchilled Welds and Welds Chilled by Liquid CO_2 in 2014-T6 Plate
(Preliminary Data)

Specimen	Test	Tensile Properties		
		Unchilled	Chilled	Improvement
5/16" Bead on	Yield (psi) Ultimate (psi) % Elongation in 2"	27,900 42,100 5.0	30,300 45,500 7.0	8.6% 8.1% 20.0%
1/2" Bead on	Yield (psi) Ultimate (psi) % Elongation in 2"	27,500 45,300 5.5	31,500 47,600 6.0	14.5% 5.8% 9.1%

It appears that there are improvements in tensile strength ranging from approximately 5% to 14% for welds chilled by CO_2 over unchilled welds, with corresponding increases in elongation. Although the observed improvement is based on limited data, it is believed that there is some justification for optimism as the tests were randomized by the fact that two thicknesses were welded, thus averaging out variables which might not have been precisely controlled.

II. ACCOMPLISHMENTS DURING THIS REPORT PERIOD

A. Summary

The principal efforts during this report period were devoted to preparation of a paper to be presented at the welding symposium on January 18-19 in Huntsville, a study on weld backing materials, and further modification of equipment for more precise control of welding variables.

B. Symposium Paper

A summary of the program with illustrative slides was prepared for presentation at the Third Welding Symposium to be held at NASA facilities in Huntsville on January 18-19, 1966.

C. Weld Backing Material Studies

Bead on plate welds were used to investigate various materials selected for application to the back side of the weld in an effort to improve the efficiency of chilling with liquid CO_2 jets without mechanical damage to the underbead from the force of the jets. Backing materials investigated included adhesive and non-adhesive glass tape, fine copper mesh, coarse copper mesh, copper foil and aluminum foil. All materials were cut into strip approximately two inches wide and twelve inches long. These strips were fastened in series over the underbead side of the plate to be welded using adhesive glass tape. Double glass tape (adhesive glass tape over non-adhesive glass tape) was placed at intervals between the materials being investigated, and additional intervals were left uncovered for comparison.

All welding and chilling variables were kept constant for each plate thickness, and macro-sections were prepared to compare the efficiency of each material for heat extraction.

By comparing the size of the cast weld nuggets as shown in the photographs of macrosections contained in Figures 1 through 4, it appears that copper foil transfers heat most efficiently. However, the size of the heat affected zone remains essentially the same for the two copper meshes, the copper foil, the aluminum foil, and the single glass tape. Therefore, final selection of the backing material to be used throughout the remainder of the program will be based on further testing to determine the relative degrees of mechanical deformation of the underbead (on actual weld seams) and the ease of application for each of these materials.

D. Modification of Equipment

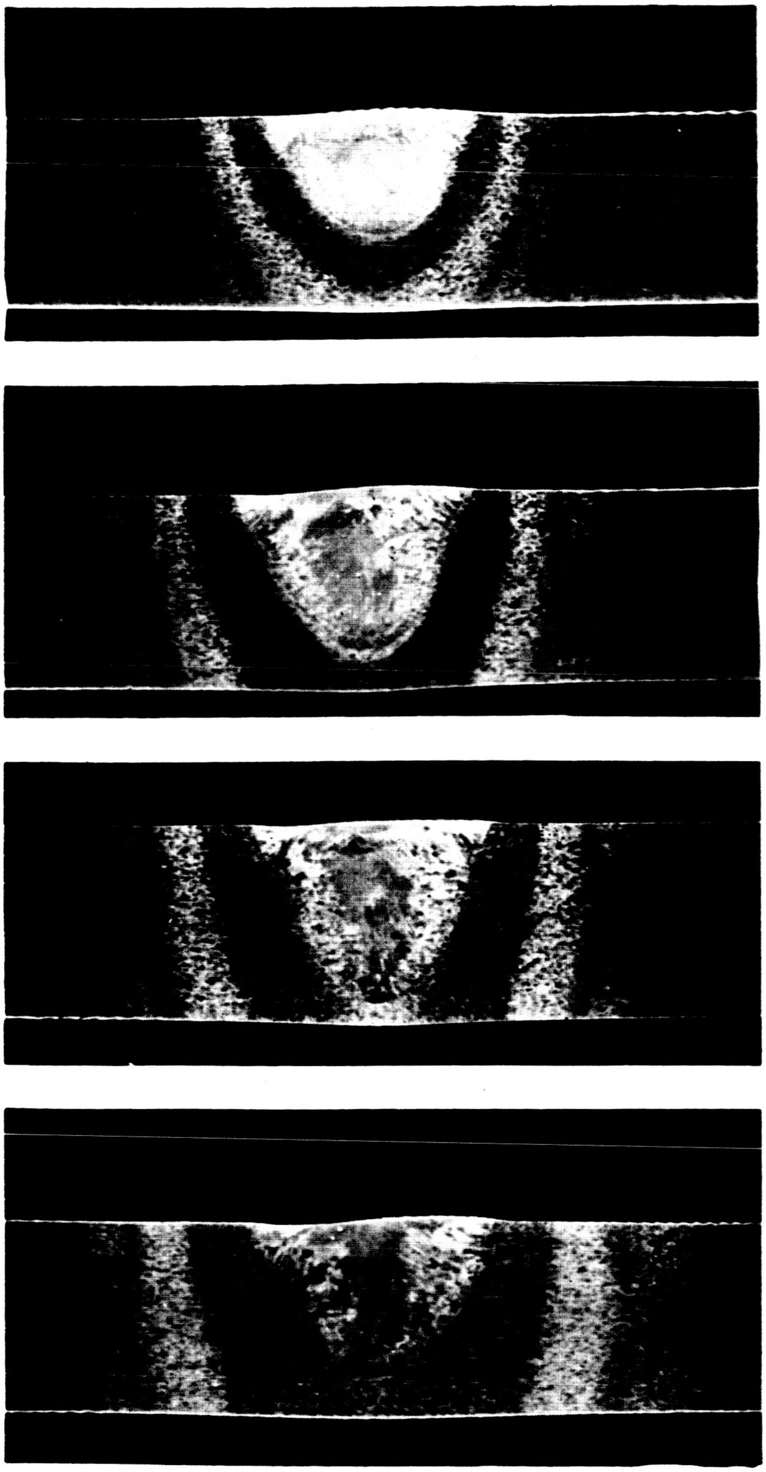
1. Electrode Positioner

a. Vernier scales were attached to the electrode holder so that the position of the electrode in both the horizontal and vertical directions (with reference to the weld panel) can be measured accurately.

b. A gauge was devised to measure the extension of the electrode from the collet.

c. In the absence of an electrode "proximity control", a feeler gauge is being utilized to set the distance between the electrode tip and the work piece. It has been necessary to make adjustments manually to maintain this distance constant (i.e., constant arc length) as welding proceeds along the length of the panel. Variations occur when the panel is not perfectly flat, due to bowing of the as-received material and/or thermal distortion during welding. Variations in electrode distance result in changes in arc voltage and welding heat input. As it is extremely important that heat input be kept constant to obtain consistent weld quality and to accurately calculate time-temperature data, this condition must be remedied. Initial steps were taken to acquire a "proximity control" which will be adaptable to the current equipment setup without extensive modification.

d. A Free Bend break test fixture was fabricated so that examination of the weld fracture can be accomplished immediately after welding, thus minimizing delays caused by waiting for X-ray and tensile test results.



1ACB-1
Chilling: Liquid CO_2
Jet System No. 1
Backing Material:
None

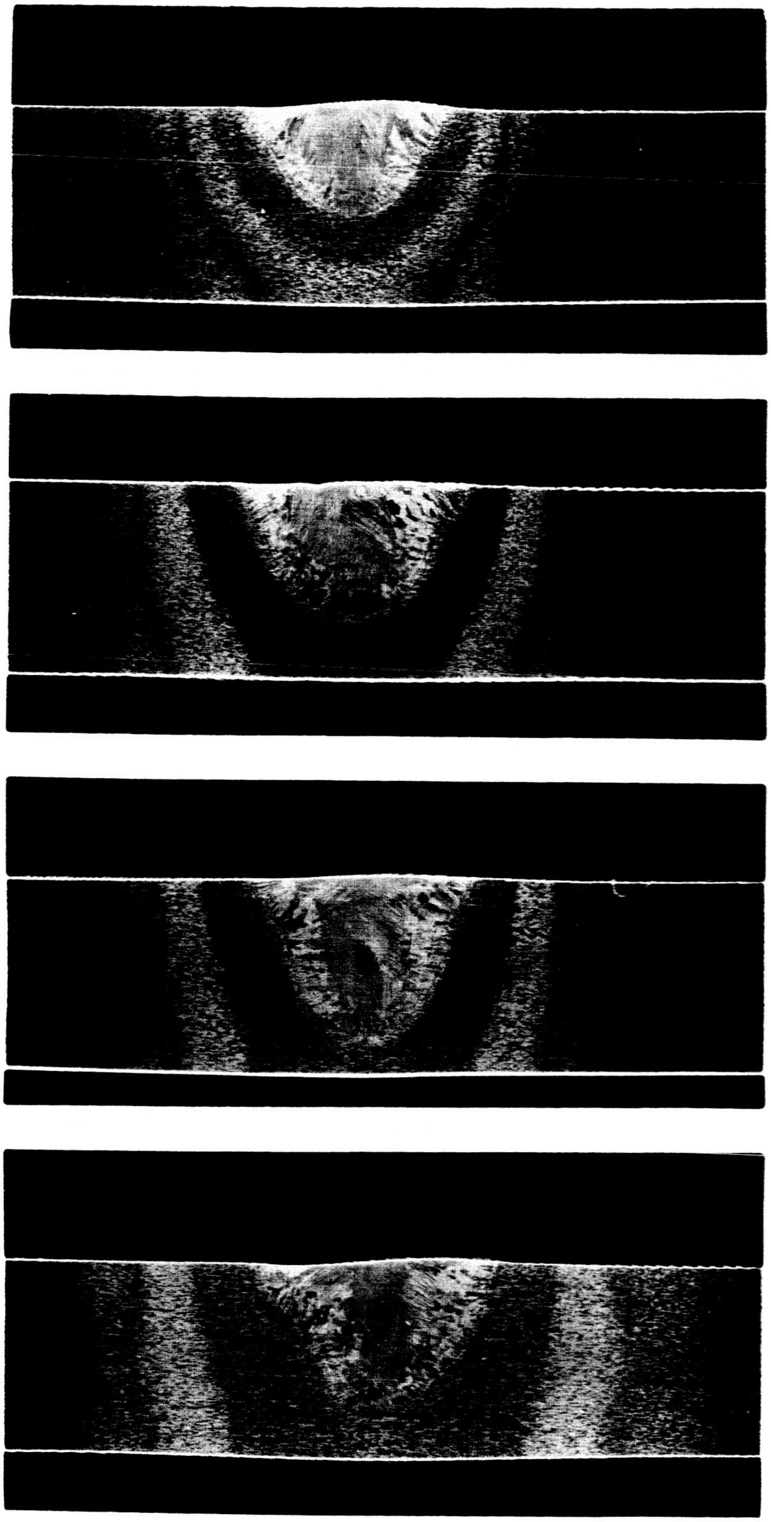
1ACB-2
Chilling: Liquid CO_2
Jet System No. 1
Backing Material:
Single Glass Tape

1ACB-3
Chilling: Liquid CO_2
Jet System No. 1
Backing Material:
Double Glass Tape

1ACB-16
Chilling: None
Backing Material:
None

12707

Figure 1. Efficiency of Glass Tape Backing Materials – Macrosections of Bead-on-Plate Welds in 5/16 INCH 2014-T6 Plate (3 X)



1ACB-1

Chilling: Liquid CO_2
Jet System No. 1

Backing Material:
None

1ACB-7

Chilling: Liquid CO_2
Jet System No. 1

Backing Material:
Copper Foil

1ACB-14

Chilling: Liquid CO_2
Jet System No. 1

Backing Material:
Aluminum Foil

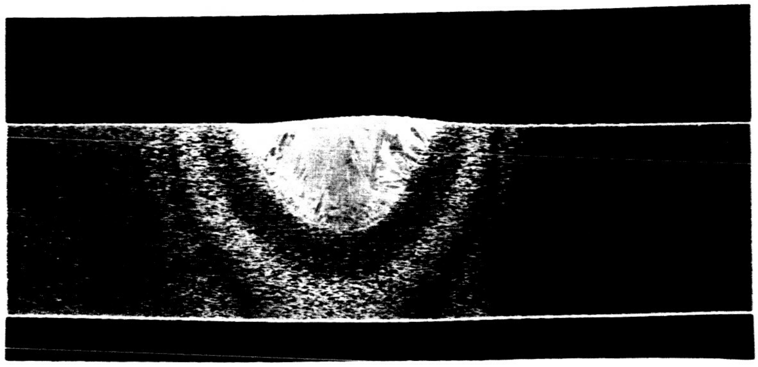
1ACB-16

Chilling: None

Backing Material:
None

12709

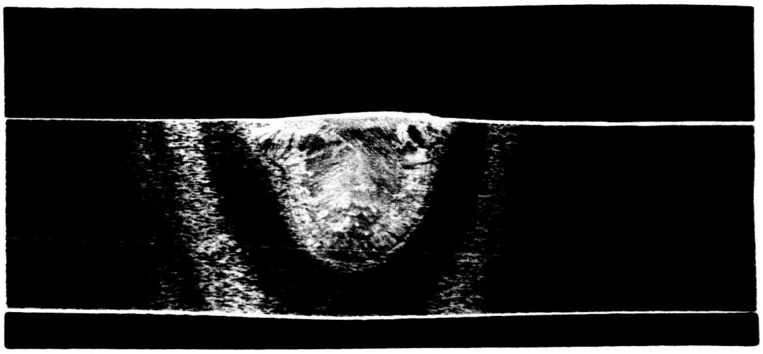
Figure 2. Efficiency of Metal Foil Backing Materials – Macrosections of Bead-on-Plate Welds in 5/16 INCH 2014-T6 Plate (3X)



1ACB-1

Chilling: Liquid CO_2 Jet System No. 1

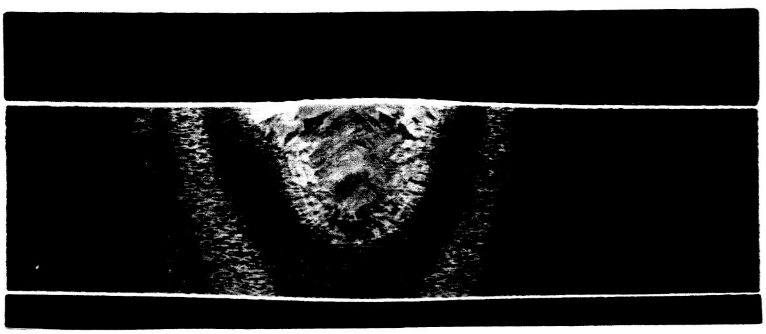
Backing Material: None



1ACB-12

Chilling: Liquid CO_2 Jet System No. 1

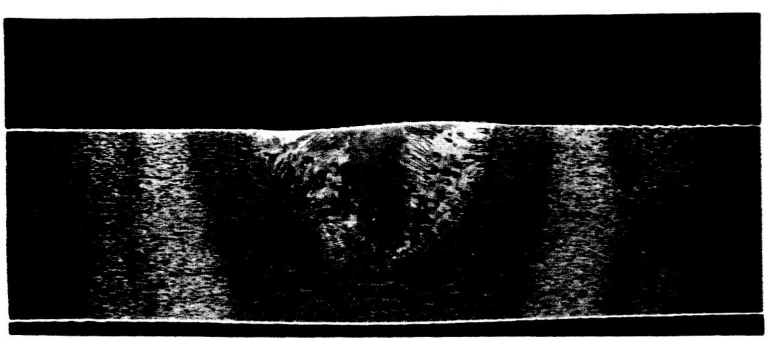
Backing Material: Coarse Copper Mesh



1ACB-13

Chilling: Liquid CO_2 Jet System No. 1

Backing Material: Fine Copper Screen



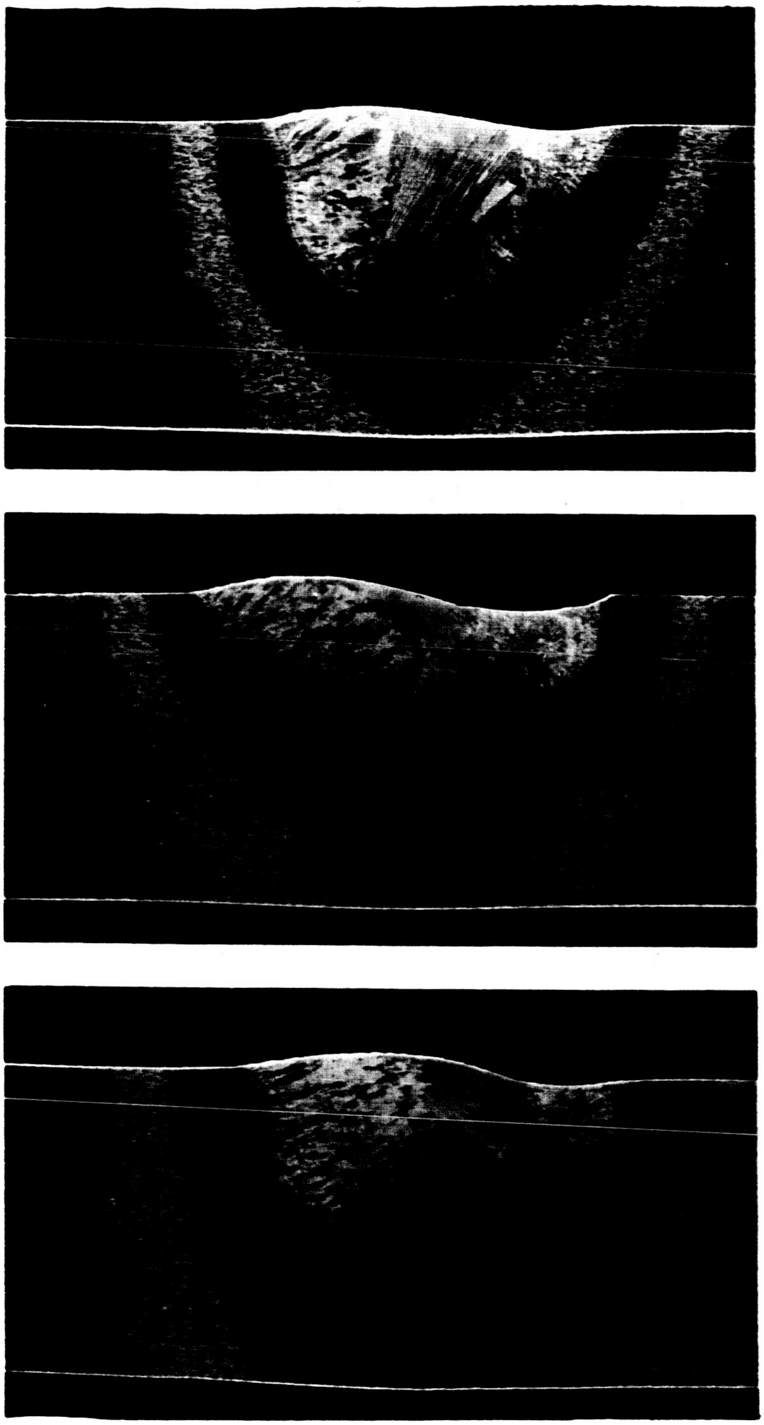
1ACB-16

Chilling: None

Backing Material: None

12710

Figure 3. Efficiency of Copper Mesh Backing Materials – Macrosections of Bead-on-Plate Welds in 5/16 INCH 2014-T6 Plate (3X)



1BC-1

Chilling: Liquid CO_2
Jet System No. 1

Backing Material:
None

1BC-2

Chilling: Liquid CO_2
Jet System No. 1

Backing Material:
Double Glass Tape

1BC-3

Chilling: None

Backing Material:
None

12708

Figure 4. Efficiency of Glass Tape Backing Materials – Macrosections of Bead-on-Plate Welds in 1/2 INCH 2014-T6 Plate (3 X)

III. ANTICIPATED WORK FOR NEXT PERIOD

During the next reporting period, it is expected that work on modification of welding equipment will be continued so that all parameters can be precisely controlled and monitored during future experimental work to obtain optimum time-temperature data.

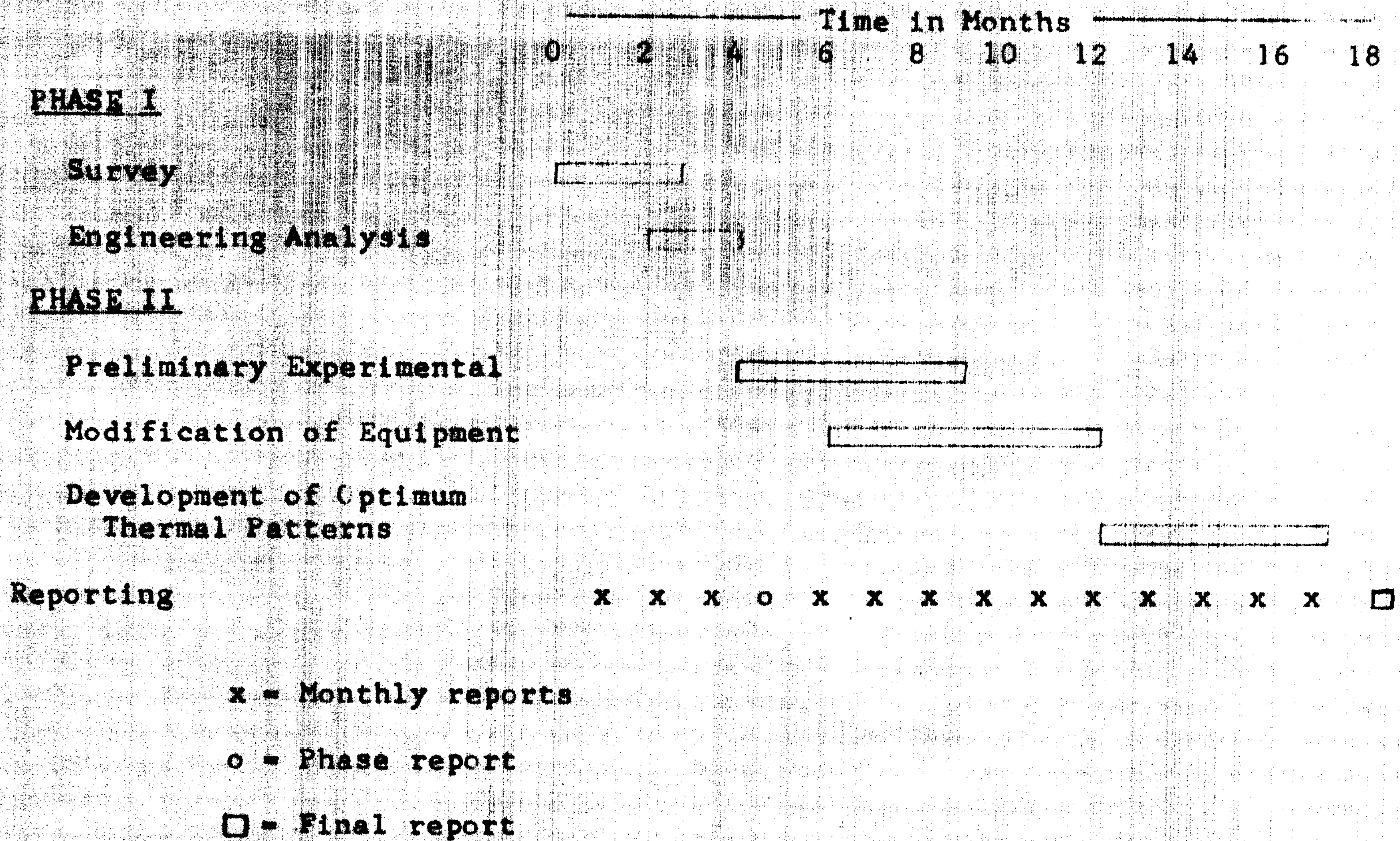
IV. SCHEDULE AND PROBLEMS ENCOUNTERED

The schedule shown on the following page was revised in October 1965.

A total of 326.0 man-hours of effort were expended during this report period, with the approximate distribution to the various functions as shown below:

Function	Engineering %	Engineering Hours	Shop %	Shop Hours
Survey	-	-	-	-
Design	25	46.0	-	-
Development	50	91.0	100	143.0
Documentation	25	46.0	-	-
Total	100	183.0	100	143.0

PROGRAM SCHEDULE
(Revised October 1965)



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