A STUDY OF METHODS FOR PREPARING CLAD 24S-T3 ALUMINUM-ALLOY SHEET SURFACES FOR ADHESIVE BONDING

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A STUDY OF METHODS FOR PREPARING CLAD 24S-T3 ALUMINUM-ALLOY SHEET SURFACES FOR ADHESIVE BONDING[1]

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SUMMARY

Comparisons were made of the effectiveness of 22 different cleaning methods in preparing 0.064-inch 24S-T3 clad aluminum-alloy sheet surfaces for bonding into lap-joint specimens with four adhesive bonding processes A, B, C, and D. The cleaning methods used included solvent treatment, abrasion, alkaline cleaning, acid etching, electrolytic cleaning, and combinations of alkaline and acid cleaning methods. The adhesive bonding processes used were considered to be representative of the types of adhesives capable of producing high-strength joints between metals.

In general, preparing clad 24S-T3 aluminum-alloy sheet surfaces for bonding joints of high-strength with any of the four bonding processes was best accomplished when using a warm sulfuric acid-sodium dichromate solution for cleaning.

With bonding process A, the best results were usually obtained when an acid cleaning solution such as hydrofluosilicic acid or sulfuric acid-sodium dichromate, or the acid deoxidizing cleaner L, was used in preparing the clad 24S-T3 aluminum-alloy sheet. Abrasion cleaning was also moderately effective in preparing the clad 24S-T3 sheet for bonding with adhesive A, but solvent cleaning or immersion in alkaline solutions was usually found to result in low-strength joints.

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With bonding process B, several of either acid or alkaline cleaning methods were found to have prepared the surfaces so that high-strength joints were obtained. Alkaline cleaning methods were generally found to result in better cleaning of the clad 24S-T3 sheets for bonding with process C or D than did acid or other cleaning methods, but several of the acid etching processes, including sulfuric acid-sodium dichromate solution, also gave very efficient surface preparation.

With the three bonding processes, B, C, and D, merely wiping the clad 24S-T3 sheet surfaces with a cloth saturated with benzene, although not resulting in as efficient cleaning as that obtained with some of the other cleaning methods, did result in bonds with joint strengths exceeding 2,000 pounds per square inch.

The efficiency of the several types of cleaning processes in preparing for bonding clad 24S-T3 sheet surfaces having various types of contamination was compared. Surfaces having sodium metasilicate stain were found to be the most difficult to bond. The acid etching process with sulfuric acid-sodium dichromate solution gave the best results in preparing the metasilicate-stained surface. Fairly good preparation of the surface for bonding was also obtained by washing this surface with benzene and then abrading it thoroughly with aluminum wool. When surfaces coated with oil and paraffin to simulate a surface contaminated with grease were washed with benzene and abraded with aluminum wool, good-quality joints were obtained, and cleaning the paraffin-oil surface with sulfuric acid-sodium dichromate solution was found to result in even better bonding. Cleaning this oil-paraffin surface with benzene and sodium metasilicate was also found to result in good joint strength when bonding with processes B or C.

Bonding directly to the side of the clad 24S-T3 sheet containing the identification lettering without prior treatment of the sheet was also investigated. Joints made to these surfaces with bonding processes B or C were found to have strengths of about 2,000 pounds per square inch, which was 65 to 80 percent of the strength of joints made with these adhesives to clad 24S-T3 sheets that were cleaned by the more elaborate cleaning processes. Joints made with bonding process A on untreated clad 24S-T3 sheets were only about half as strong as those obtained with the other two bonding processes under the same conditions.

INTRODUCTION

Experience in bonding a metal such as aluminum to itself or to other materials has shown that occasionally bonds result that fail considerably in adhesion to the metal. Frequently these faulty bonds have been attributed to improper cleaning of the metal. It has been acknowledged for some time that cleaning the metal is an important factor in bonding high-strength joints, but present knowledge of the many variables involved does not permit fabricators to select simple methods that will produce metal surfaces that are properly and uniformly cleaned for bonding. Available information on currently used methods for cleaning metal prior to bonding was collected from various manufacturers and processors and assembled. Results of this survey showed that a number of procedures for cleaning metals prior to bonding had been adopted, but that opinions varied as to the effectiveness and limitations of some of these methods. Some of the cleaning methods that were described for certain adhesives required excessive changes in procedure when shifting from one bonding process to another. Often there was no agreement among manufacturers of one chemical type of adhesive as to the best method for preparing a given metal for bonding. Included among the recommended cleaning processes were abrasion, solvent, alkaline, acid, or electrolytic cleaning. These methods may be used separately or in combination.

The aluminum alloys, 24S-T3 (bare), clad 24S-T3, 75S-T6 (bare), and clad 75S-T6 are the principal alloy sheet metals now used in aircraft. Of these, the clad alloys are used for the most part. It was therefore the purpose of this study to investigate the effectiveness of different cleaning methods in preparing one of these sheet alloys, clad 24S-T3, for bonding with several adhesive processes in order to determine the need for changing cleaning processes when replacing one bonding process with another. These results should then be applicable to other aluminum alloys, both clad and bare, but since the cladding with 24S-T3 is pure aluminum and the cladding with 75S-T6 is aluminum alloy containing approximately 1 percent zinc, tests with these other alloys should be made to verify the results before doing any extensive bonding.

The study of cleaning methods was divided into two parts. In the first part the clad 24S-T3 sheets were used as received, and in the second part certain contaminants were purposely deposited on the metal before cleaning it by some of the methods that gave most promise in part I. Bonding processes are described under part I, and some of these same processes were also used in part II.

PART I. STUDIES OF VARIOUS METHODS OF CLEANING CLAD 24S-T3 ALUMINUM-ALLOY SHEETS AS NORMALLY RECEIVED

Procedure

Type and Number of Test Specimens

Test panels were prepared from two 0.064-inch clad 24S-T3 aluminum-alloy sheets, 4 by 6 inches in size, by overlapping and bonding them for 1 inch along the 6-inch dimension. The clad 24S-T3 sheets used throughout the study were from one manufacturer and conformed to Army-Navy Aeronautical Specification AN-A-13. Two panels were prepared for each bonding variable investigated. Five test specimens, each 1 inch wide, were cut from each panel, with allowance for at least 1/4 inch along each edge of the panel for trimming. A total of 10 specimens was thus available for each variable studied.

Bonding Processes

Four adhesive bonding processes, considered representative of the types capable of producing high-strength joints between metals, were used in preparing the lap-joint specimens. The bonding processes included two, A and B, in which were used adhesives A and B, believed to consist of polyvinyl resins modified with phenol resins; a process, C, in which was used a phenol-synthetic rubber adhesive, C; and a process, D, in which were used the adhesive C as a primer on each metal face and an intermediate-temperature-setting phenol-resin adhesive, D, as the secondary adhesive.

Bonding Conditions

The bonding conditions (amount of spread, assembly, precure, and cure) used were either those recommended by the adhesive manufacturer or those that had been found satisfactory in preliminary tests at the Forest Products Laboratory. The conditions for each bonding process were kept constant throughout the investigation of the various cleaning methods in order to eliminate, insofar as possible, the effect of variables other than the condition of the surface and the cleaning method used.

The conditions for the various bonding processes were as follows:

Process A.--Adhesive A was supplied as a liquid resin and as a separate powder. One light coat of adhesive A liquid was brushed on each clad 24S-T3 aluminum-alloy sheet surface, the adhesive A powder was then immediately sprinkled on the wet surface, and the excess powder was removed by shaking. The adhesive layer was air-dried for approximately 20 hours, and then the panels were assembled and pressed for 15 minutes at a temperature of 300° F. under a pressure of 200 pounds per square inch.

Process B.--Adhesive B was sprayed on each faying surface to produce a film thickness of approximately 0.004 inch. Eight coats were generally required, depending on the adjustment of the spray gun. Following an open-assembly period of 20 hours, the adhesive film was force-dried for 45 minutes at a temperature of 200° F., precured in the hot press for 9 minutes at 200° F. without pressure, and then the joints were pressed for 15 minutes at 300° F. under a pressure of 200 pounds per square inch.

Process C.--Eight coats of adhesive C were sprayed on each faying surface with an elapsed time of 3 minutes between coats. After an open-assembly period of 18 to 24 hours, the panels were pressed for 25 minutes at a temperature of 325° F. under a pressure of 200 pounds per square inch.

Process D.--Eight coats of adhesive C were sprayed on each faying surface with an elapsed time of 3 minutes between coats. After an open-assembly period of 18 to 24 hours, the panels were cured in an oven for 25 minutes at a temperature of 325° F. One medium heavy coat of adhesive D was brushed on both primed metal surfaces, which had been cooled to room temperature following the curing of the primer. Following an open-assembly period of 16 to 20 hours for adhesive D, the panels were pressed for 1 hour at a temperature of 240° F. under a pressure of 200 pounds per square inch.

Cleaning Methods

In this part of the study all clad 24S-T3 aluminum-alloy sheets were from one source (E) and were used as received, except that the 4- by 6-inch sheets were washed on both sides with a clean cloth saturated in benzene to remove the identification lettering and any other contamination that might be on the sheet. Four of the 4- by 6-inch sheets were cleaned, and two bonded panels were prepared from them for each cleaning method and bonding process. The cleaning methods investigated were as follows:

Method A--Benzene Wipe.--In method A no treatment was given the clad 24S-T3 sheet surfaces other than the benzene wipe used on all sheets included in this part of the study. This method was used for the controls.

Method B--Abrasion Cleaning.--In method B the clad 24S-T3 aluminum-alloy sheet surfaces were abraded in one of the following ways:

(1) By light sandblasting with clean sand for approximately 1/2 minute. The surfaces were then wiped with a clean, dry cloth. Surfaces outside of the bonding area were masked to prevent destruction of the clad layer.

(2) By hand rubbing in parallel strokes with No. 00 aluminum wool (dry) and then wiping with a clean, dry cloth.

(3) By hand rubbing with an iron-free abrasive cloth (grit No. 80) and then wiping with a clean, dry cloth.

Note: Iron-free abrasives were selected in order to avoid use of materials known to promote corrosion of clad 24S-T3 aluminum alloy in service.

Method C--Solvent Cleaning.--In method C the metal was cleaned in one of the following ways:

(1) By immersing for 3 minutes in a solution made by mixing 5 percent by weight of the adhesive as received with 95 percent of the same solvent as used in the original adhesive.

(2) By vapor degreasing with stabilized trichloroethylene (product F), meeting the requirements of Army-Navy Aeronautical Specification AN-T-37a, in a commercial degreasing apparatus.

Method D--Alkaline Cleaning.--In method D the metal was cleaned in one of the following ways:

(1) By scouring with a fiber-bristled brush and a hot borax powder solution (product G) (2.0 ± 0.5 ounces per gallon of water at 130° F.).

(2) By immersing for 5 minutes in a hot (160° to 180° F.) solution of the following composition:

3.6 ± 0.5 ounces of sodium metasilicate
0.4 ± 0.1 ounce of wetting agent (product H)
1 gallon water

(3) By immersing for 5 minutes in a hot (160° to 180° F.) solution of the following composition:

6.0 ± 1.0 ounces of an inhibited alkaline detergent cleaner for aluminum (product I)
1 gallon water

(4) By immersing for 5 minutes in a hot (180° to 200° F.) solution of the following composition:

6.0 ± 1.0 ounces of an alkaline etching cleaner for aluminum (product J)
1 gallon water

(5) By immersing for 10 minutes at room temperature in a solution of the following composition:

4.0 ± 1.0 ounces of sodium hydroxide
1 gallon water

(6) By immersing for 5 minutes in a hot (185° to 212° F.) solution of the following composition:

5.0 ± 1.0 ounces of a soap meeting Navy Aeronautical Specification C-152 (product K)
1 gallon water

Method E--Acid Cleaning.--In method E the metal was cleaned in the following ways:

(1) By immersing for 10 minutes in a warm (140° to 160° F.) solution of the following composition:

45.0 ± 1.0 ounces concentrated sulfuric acid (specific gravity, 1.84)
4.5 ± 0.5 ounces sodium dichromate
1 gallon water

(2) By immersing for 3 minutes in a warm (140° to 160° F.) solution of the following composition:

7.0 ± 1.0 ounces chromic acid
1 gallon water

(3) By immersing at room temperatures for 3 minutes in a solution of the following composition:

10 percent by volume concentrated phosphoric acid (85 percent H_3PO_4)
40 percent by volume butyl alcohol
30 percent by volume isopropyl alcohol
20 percent by volume water

(4) By immersing for 5 minutes at 140° to 160° F. in a solution of the following composition:

10.0 ± 0.5 ounces of commercial phosphoric acid (85 percent H_3PO_4)
3.0 ± 0.5 ounces of chromic acid
0.20 ± 0.05 ounces of wetting agent (product H)
1 gallon water

(5) By immersing for 5 minutes in a hot (160° to 180° F.) solution of the following composition:

6.0 ± 1.0 ounces of a deoxidizing cleaner (product L)
1 gallon water

(6) By immersing for 8 to 10 minutes at room temperature in a solution of the following composition:

5.0 ± 0.5 ounces of commercial hydrofluosilicic acid (27 percent H_2SiF_6)
0.20 ± 0.05 ounces of wetting agent (product H)
1 gallon water

Method F--Electrolytic Cleaning.--The metal was cleaned electrolytically by immersion for 5 minutes at a temperature of 130° to 190° F. in a solution of the following composition:

40 percent by volume sulfuric acid (specific gravity, 1.84)

40 percent by volume phosphoric acid (85 percent H_3PO_4)

20 percent by volume water

A current density of 0.3 to 0.5 amperes per square inch of anode surface was applied during the immersion in the solution, with the clad 24S-T3 aluminum-alloy sheet as the anode and a copper sheet as the cathode.

Method G--Combinations of Cleaning Methods.--In method G the metal was cleaned by one of the following combinations of methods:

(1) D(1) (borax wash), followed by D(2) (sodium metasilicate), and then by E(2) (chromic acid).

(2) D(2) (sodium metasilicate), followed by E(2) (chromic acid).

(3) D(3) (detergent cleaner I), followed by E(6) (hydrofluosilicic acid).

In all of the methods by which the metal was cleaned by abrasion or by solvents, the metal was bonded without any further treatment. In the cleaning methods where water solutions were used, care was taken to wash the clad 24S-T3 aluminum-alloy sheets thoroughly with tap water upon removal from the cleaning baths in order to remove all the chemicals before they could dry on the sheets. In combination treatments, the clad 24S-T3 sheets were rinsed in water after being removed from each aqueous bath. Following removal from the last cleaning bath in each process, the metal was thoroughly washed with hot water and was then quickly air-dried. Throughout the study, observations were made and recorded of the condition of the water film on the surface when the metal was removed from the rinsing water. The clean clad 24S-T3 sheets were dried at normal room temperatures for 1 hour before application of the first coat of adhesive to the surface. In no instance were the clean sheets allowed to remain for more than 4 hours before application of the adhesive.

All solutions were used in vessels of nonreactive materials. Precautions were taken to see that none of the solutions were contaminated, that the cleaning solutions were agitated to prevent concentration or temperature stratification, that the surfaces to be cleaned did not touch each other or the containing vessel, and that the clean clad 24S-T3 aluminum-alloy sheet surfaces did not become contaminated during the interval between cleaning the metal and the application of the adhesive. Determinations were made of the pH values of the various solutions used in the cleaning.

Equipment limitations prevented preparation of specimens by all of the cleaning methods for a particular bonding process at one time. It was therefore necessary to repeat each bonding process on each of several days with use of only a few of the cleaning processes on each day. In order to insure that the quality of the joints in the several series of runs made with each bonding process was the same, a control group of two panels cleaned with method E(1) (sulfuric acid-sodium dichromate) was prepared with each bonding process on each day that this bonding process was being used in investigating methods of cleaning.

Testing

The two lap-joint panels prepared with each bonding process and cleaning method were sawed into a total of 10 individual test specimens in such a manner that the joints were not overheated or subjected to excessive mechanical damage in cutting. The specimens were then loaded to failure in tension at a rate of approximately 600 pounds per minute in a machine in which the ends of the specimen were held in testing grips of the type shown in figure 1. Jaws in the grips were offset in such a way that the center of both grips and the adhesive line were in alinement. Testing was done at a temperature of 80° ± 5° F. The failing load and the estimated areas (expressed as percentages of total area of joint) of adhesion failure, of cohesion failure, and of lack of contact were recorded.

PART II. STUDIES OF SOME OF THE MORE PROMISING CLEANING METHODS IN TREATMENT OF CONTAMINATED SURFACES OF CLAD 24S-T3 ALUMINUM-ALLOY SHEETS

Procedure

Surface Conditions

As a second part of this study, several of the cleaning methods representative of the types used in part I were used in cleaning clad 24S-T3 aluminum-alloy sheets having several types of surface contamination. The surface conditions were: (1) sheets as normally received, (2) sheets as received and then coated with a greasy layer to simulate a surface condition such as might be encountered after long storage, and (3) sheets having stains of the type obtained when alkaline cleaning solutions are allowed to dry on the surface. The greasy layer (2) was obtained by dipping the sheets, as received, for 1 minute in a solution of 50 parts by weight of carbon tetrachloride, 10 parts petroleum paraffin, and 25 parts clean S.A.E. No. 10 oil, and by then air-drying the solution. The stained sheets (3) were prepared by dipping the sheets, as received, in a solution of sodium metasilicate as used in method D(2) of part I, and by then allowing the solution to dry on the surface without rinsing after removal from the bath. In the preparation of each of the contaminated surfaces, the sheet was washed with benzene before any contaminant was applied.

Cleaning Methods

The clad 24S-T3 sheets (4 by 6 inches) of each kind of surface condition were then cleaned, before being bonded with one of the three bonding processes, A, B, or C, by methods that were the same as methods A, B (2), C (2), D (2), and E (1) in part I, except that a new method, H, was added. In method H the surface was not cleaned prior to bonding, and when the clad 24S-T3 sheet was bonded as received, the bonding was done on the lettered side.

The rinsing, drying, and general precautions taken in part I of this study were also used in cleaning specimens for part II.

Testing

Two bonded panels, providing a total of 10 specimens, were usually prepared for each surface condition, cleaning method, and bonding process. Because of equipment limitations a series of bonding runs was made on different days in the same manner as in part I of this study, and on each day a control group of specimens was prepared from clad 24S-T3 aluminum alloy sheets, as received, that were washed with benzene and then cleaned with sulfuric acid-sodium dichromate.

The procedure for testing was as described in part I.

Results

In table 1 are given the results and the types of failures obtained in tests of the clad 24S-T3 aluminum-alloy joints cleaned by the 22 cleaning methods and bonded with the 4 gluing processes described in part I. The pH of the fresh solutions used in cleaning the clad 24S-T3 sheets, the appearance of the sheet surfaces after cleaning, and the appearance of the water film obtained when water was rinsed over the sheet surface after cleaning, are also given.

Of the 22 cleaning processes investigated for cleaning aluminum, the sulfuric acid-sodium dichromate cleaning method, E (1), generally resulted in joints having the highest strengths. This cleaning method was included as a control in each of the several series of bonding runs that were found necessary in completing the evaluation of all of the cleaning methods used with each of the bonding processes. The series numbers for each bonding process are designated in table 1. The average shear strength for several series of 1-inch lap joints cleaned with the sulfuric acid-sodium dichromate process was 3,300 pounds per square inch for bonding process A, 2,940 for bonding process B, 2,690 for bonding process C, and 2,590 for bonding process D. If the results with each bonding process on clad 24S-T3 sheets cleaned by method E (1) may be considered as a standard, the relative joint quality may be expressed, for each of the same adhesives on metal cleaned by the other methods, as a percentage of the value obtained for method E (1) in this same bonding series. Results are expressed in this manner in table 2.

When no treatment other than a wash with benzene was used in preparing the surfaces of the clad 24S-T3 sheets as received, bonding processes B, C, and D gave joint strengths that exceeded 2,000 pounds per square inch. These strengths were approximately 70 to 90 percent of the strengths obtained when the sheets were cleaned with the sulfuric acid-sodium dichromate method, E (1). When the metal was cleaned with a benzene wash only and was then bonded with process A, an average joint strength of 1,632 pounds per square inch was obtained, which was somewhat lower than that obtained with the other three bonding processes, and which was approximately 50 percent of the strength obtained when using this bonding process to bond clad 24S-T3 sheets cleaned with sulfuric acid and sodium dichromate. Since it is of interest to know, for each adhesive process, how much better or poorer results may be with other cleaning methods when compared with this simple benzene-wash method (A), these comparisons are presented in table 3 as percentages of the average joint strength obtained when the sheets were cleaned by merely washing with benzene.

When clad 24S-T3 sheets were benzene-washed and then abraded by sandblasting, rubbing with aluminum wool, or rubbing with abrasive cloth, the joints bonded with processes A and D were somewhat stronger than those cleaned only with benzene; whereas no significant differences between these methods of cleaning were noted with the other two bonding processes. Although joints prepared from the sheets cleaned by these mechanical abrasion methods were not so good as those cleaned by the sulfuric acid-sodium dichromate method or by some of the other acid and combinational methods, they were often superior to joints in which the sheets were cleaned by some of the alkaline or solvent cleaning methods.

Dipping the clad 24S-T3 sheets in a dilute solution of the adhesive after the benzene wash and before bonding (C(1)), as was recommended by one adhesive manufacturer, was found to have no significant advantage over the benzene wash, and for three of the bonding methods (B, C, and D) lower bond strengths resulted.

Vapor degreasing with stabilized trichloroethylene (C(2)) had no marked advantage over the benzene wash with bonding processes A and B, had some moderate advantage with bonding process C, and resulted in weaker joints with bonding process D. Note: Good cleaning of metals for bonding has been reported using vapor degreasing methods. The inconsistent results obtained in this study might be attributed to the small size and lower efficiency of the vapor degreasing unit used in this investigation. When clad 24S-T3 sheets cleaned by the two solvent cleaning methods, C(1) and C(2), were tested by allowing water to run over the dry surface, water-film breaks were obtained that indicated imperfect cleaning.

The six alkaline cleaning solutions used in preparing clad 24S-T3 aluminum-alloy sheets for bonding gave widely varying results with the four bonding processes. Of those investigated, immersion in a solution of sodium metasilicate (D(2)) or in a soap conforming to Navy Specification C-152 (D(6)) prior to bonding with process B, C, or D gave an improvement over the results obtained when the surfaces were merely washed with benzene, and in several instances the joint quality was equal to that obtained when sulfuric acid-sodium dichromate cleaning (E(1)) was used. In bonding with process A, scrubbing with borax powder (D(1)) or immersion in sodium metasilicate solution (D(2)) gave some improvement in joint strength over that obtained by washing with benzene, but joints of clad 24S-T3 sheets cleaned with the soap, Navy Specification C-152 (D(6)), were poor, although results with sheets cleaned in this manner and bonded with the other three bonding processes were good. Two of the more alkaline cleaning methods D(4) and D(5) gave consistently poor results with all four bonding processes. The cleaning process D-4 was found to result in a loose black film deposit after rinsing in water. High pH values are apparently not directly correlated with poor cleaning behavior, however, since the Navy soap in method D(6) had the highest pH measured and yet gave good results with three of the four bonding processes. The alkaline detergent cleaner I (D(3)) resulted in low-quality joints when bonding with process A, and with the other three bonding processes it gave strengths approximately the same as those obtained on surfaces that were merely washed with benzene. It is worth noting, however, that joints made with cleaning method G(3), in which treatment with the alkaline cleaner I (D(3)) was followed by rinsing in water and by an acid treatment (E(6)), were consistently high in strength. This improvement, after an acid rinse, was also noted with bonding process A and cleaning method G(2), in which chromic acid treatment followed the sodium metasilicate bath.

Of the acid cleaning methods investigated, several gave very good results with certain bonding processes. For adhesive A, both the deoxidizing cleaner L (E(5)) and hydrofluosilicic acid (E(6)) solutions gave results nearly equivalent to the average results obtained with sulfuric acid-sodium dichromate solution (E(1)); and phosphoric acid (E(3)) gave results equal to those obtained with abrasive cleaning methods and better than those obtained with any of the solvent or alkaline cleaning methods investigated. For adhesive B, hydrofluosilicic (E(6)) or phosphoric-chromic acid (E(4)) cleaning resulted in joint strengths that were nearly equivalent to those obtained with the sulfuric acid-sodium dichromate method or with any of the better alkaline cleaning methods, and phosphoric acid (E(3)) and deoxidizing cleaner L (E(5)) gave only slightly lower strengths. In both bonding processes C and D, phosphoric acid cleaning (E(3)) gave an improvement in joint strength over the strengths obtained with benzene washing (A), and process C gave equally good results with the chromic acid method E(2). In these cases the strengths were nearly the same as that obtained with sulfuric acid-sodium dichromate cleaning. Generally, chromic acid (E(2)) and phosphoric-chromic acid (E(4)) were the least effective of the acid treatments.

Electrolytic cleaning was investigated[3] and was found to result in low and inconsistent joint strengths, except for bonding process D, in which results were equal to those obtained when the clad 24S-T3 sheets were cleaned by the sulfuric acid-sodium dichromate method E(1).

Several combinational cleaning methods were also investigated in which an alkaline cleaning was followed by cleaning in an acid solution. The combinational methods used with each of the four bonding processes generally gave joint strengths that were essentially equal to or only slightly lower than the strength of joints cleaned with sulfuric acid and sodium dichromate (E(1)). Generally, the combination of two cleaning methods gave better results than either method used alone.

In tables 4, 5, and 6 are given the shear-test results and the types of failures obtained in part II on joints made to clad 24S-T3 aluminum-alloy sheets having three types of surface condition, the normal surface as received, a surface contaminated with paraffin and oil, and a surface contaminated with metasilicate stain. Six types of cleaning are compared for preparing these surfaces for bonding with three processes. Series numbers of the bonding runs made on different days are given as in table 1.

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[3]The investigation of electrolytic cleaning was limited to the use of one cleaning method. The use of other electrolytic cleaning methods, or a variation in the conditions of the method used, might give improved results.

Generally, the quality of joints on clad 24S-T3 sheets, as received and then cleaned by the various methods, agreed quite closely with those results obtained under the same conditions in part I (table 1). When joints were prepared with clad 24S-T3 sheets as received and the bonding was done to the side of the sheet having identification printing, good results were obtained with process C (2,380 p.s.i.) and with process B (1,954 p.s.i.). Process A showed poor bonding to this surface. In general, throughout the work of part II, process A was also found to be somewhat more exacting as to the method of surface preparation than the other two bonding processes.

The surfaces having metasilicate stain were found to be the most difficult to clean and bond properly. Acid cleaning with sulfuric acid-sodium dichromate solution E(1) gave the best cleaning of this type of surface, and the joint strengths obtained closely approached those obtained when this cleaning method was used in preparing clad 24S-T3 sheets, as received, for bonding. The use of a benzene wash followed by abrasion with aluminum wool was found to give good results in cleaning the sodium-metasilicate-stained metal, but it was not quite so efficient as the use of sulfuric acid-sodium dichromate cleaning.

The sulfuric acid-sodium dichromate cleaning following a benzene wash was found to be the most consistently effective method of preparing clad 24S-T3 aluminum-alloy sheet surfaces contaminated with an oil-paraffin film for bonding with any of the three bonding processes investigated. Sodium metasilicate also produced reasonably efficient cleaning of this type of surface for bonding with processes B or C, but poor bonding was obtained when the clad 24S-T3 sheets were cleaned by this method for bonding with process A. Good results were also obtained when surfaces having oil-paraffin contamination were cleaned by washing with benzene and abrading with aluminum wool (B(2)) and were then bonded with adhesives A or B. The use of a benzene wash alone or of a vapor-degreasing process was found, in some instances, to improve the bonding of the clad 24S-T3 sheets having oil-paraffin contamination more than the bonding obtained when these contaminated surfaces were not cleaned at all. It was noted throughout this study, however, in both parts I and II, that results were often so inconsistent when using these solvent methods that it was difficult to predict whether or not solvent treatment would improve the bonding properties of a surface.

The conclusions on the effectiveness of various cleaning methods used in parts I and II were based on the results obtained in these present tests with cleaning methods used in the manner described under the test procedures. If the concentration or temperature of the solution, or the time of immersion or degree of treatment were changed, some of the results might be expected to vary from those reported.

Table 1.--Comparison of the effects of different cleaning methods on the strengths of 1-inch lap joints of 0.064-inch clad 24S-T3 aluminum-alloy sheets joined with four bonding processes

Cleaning method[1]	pH[2]	Appearance[3] of surface	Water[4] film test	Bonding process A: Average shear strength[5]	A: Type of failure[6] Ad.	A: Co.	A: N.c.	A: Series No.[7]	Bonding process B: Average shear strength[5]	B: Type of failure[6] Ad.	B: Co.	B: Series No.[7]	Bonding process C: Average shear strength[5]	C: Type of failure[6] Ad.	C: Co.	C: N.c.	C: Series No.[7]	Bonding process D: Average shear strength[5]	D: Type of failure[6] Ad.	D: P.c.	D: P.s.	D: Series No.[7]
				P.s.i.	Percent	Percent	Percent		P.s.i.	Percent	Percent		P.s.i.	Percent	Percent	Percent		P.s.i.	Percent	Percent	Percent	
A. Benzene wash, no other treatment	....	Shiny	Broken	1,632	93	[illegible]	7	5	2,002	85	15	3	2,479	7	84	9	1	2,027	75	25	0	4
B. Abrasion cleaning																						
(1) Sandblasting	....	Finely pitted	Broken	2,474	98	2	0	5	2,330	100	0	3	....	....	....	....	......	....	....	....	....	......
(2) Aluminum wool	....	Dull and scratched	Continuous	2,268	99	1	0	5	1,888	76	24	3	2,424	96	4	0	1	2,546	74	1	25	1
(3) Iron-free abrasive cloth	....	Dull and scratched	Continuous	2,477	93	7	0	5	1,912	91	9	3	2,178	93	0	7	1	2,522	99	1	0	1
C. Solvent cleaning																						
(1) Five percent solution of adhesive in solvent	....	Thin film of adhesive on surface	Broken	1,760	91	7	2	5	1,052	88	12	1	2,160	83	9	8	2	1,780	61	3	36	2
(2) Vapor degreasing	....	Shiny	Broken	1,876	77	23	0	7	1,988	56	44	4	2,768	26	72	2	2	1,308	70	10	20	3
D. Alkaline cleaning																						
(1) Borax powder	8.79	Shiny	Broken	2,318	59	41	0	7	2,118	53	47	6	1,744	93	6	1	2	2,210	47	53	0	2
(2) Sodium metasilicate	10.06	Shiny	Continuous	1,985	85	8	7	3	2,916	54	46	1	2,703	0	96	4	3	2,310	0	42	58	2
(3) Detergent cleaner I	10.02	Shiny	Continuous	1,150	88	6	6	3	2,178	77	23	1	2,479	29	65	6	3	1,878	74	8	18	3
(4) Alkaline cleaner J	10.93	Loose black film	Continuous	476	100	0	0	2	40	100	0	4	526	98	0	2	4	108	100	0	0	5
(5) Sodium hydroxide	10.93	White and dull	Continuous	1,414	97	3	0	1	240	100	0	2	1,630	99	0	1	4	1,722	100	0	0	6
(6) Soap K, Navy Specification C-152	Over 11	Shiny	Continuous	589	80	20	0	8	2,678	47	53	6	2,436	59	37	4	4	2,888	30	70	0	6
E. Acid cleaning																						
(1) Sulfuric acid and sodium dichromate	Less than 0.5	Dull	Continuous	3,520	93	7	0	1	2,834	69	31	1	2,674	15	83	2	1	2,613	0	53	47	1
				3,660	84	16	0	2	3,015	57	43	2	2,710	30	65	5	2	2,594	0	38	62	2
				3,746	82	17	1	3	2,924	28	72	3	2,768	24	72	4	3	2,506	36	46	18	3
				3,468	83	17	0	4	2,858	53	47	4	2,504	62	35	3	4	2,850	2	97	1	4
				3,368	91	9	0	5	2,570	68	32	5	2,888	47	49	4	5	2,522	66	33	1	5
				2,746	34	66	0	6	3,032	37	63	6	2,568	28	66	6	6	2,730	0	53	47	6
				3,402	24	76	0	7	3,324	55	45	7	2,727	50	43	7	7	2,538	47	48	5	7
				2,741	39	61	0	8	....	....	....	......	....	....	....	....	......	2,434	0	45	55	8
				3,038	56	44	0	9	....	....	....	......	....	....	....	....	......	2,550	2	39	59	9
(2) Chromic acid	.8	Shiny	Broken	1,774	98	2	0	1	2,108	76	24	1	2,516	22	72	6	3	1,546	80	2	18	3
(3) Phosphoric acid	.92	Shiny	Continuous	2,536	93	7	0	1	2,313	32	68	4	2,720	10	89	1	3	2,728	12	88	0	4
(4) Phosphoric and chromic acid	.92	Shiny	Broken	1,514	82	16	2	2	2,783	54	46	2	1,902	98	0	2	5	1,354	100	0	0	7
(5) Deoxidizing cleaner L	1.1	Dull	Continuous	2,996	83	15	2	2	2,510	47	53	4	1,844	83	15	2	4	2,044	100	0	0	5
(6) Hydrofluosilicic acid	1.78	Dull	Broken	3,042	81	19	0	2	2,952	49	51	2	2,224	83	13	4	5	1,746	83	17	0	7
F. Electrolytic cleaning	....	Highly polished	Continuous	1,303	93	7	0	6	1,458	98	2	5	1,653	77	20	3	6	2,486	22	38	40	8
G. Combinations of cleaning																						
(1) Borax-sodium metasilicate-chromic acid	....	Shiny	Continuous	2,738	75	25	0	9	2,742	48	52	7	2,734	8	85	7	7	2,504	1	48	51	9
(2) Sodium metasilicate-chromic acid	....	Shiny	Continuous	2,810	73	27	0	9	2,380	66	34	7	2,491	22	59	19	7	2,526	0	17	83	9
(3) Detergent cleaner I-hydrofluosilicic acid	....	Dull	Continuous	2,818	30	70	0	9	2,724	60	40	7	2,396	66	27	7	7	2,494	1	40	59	9

[1]The metal surfaces were washed with benzene before being cleaned with each of the cleaning methods. The solution temperatures and concentrations and the cleaning procedures involved in each of the cleaning methods are described in the text of the report. It should be noted that both concentration and temperature variations between different solutions of one type make direct comparison of components inadvisable.

[2]pH value of the fresh solution at room temperature as determined by meter with glass electrode. Only aqueous solutions were measured.

[3]As observed by the unaided eye, the appearance of the surface may be considered an indication of the relative effects of the treatments on the surface of the metal.

[4]A water-film test was made by rinsing with water a sample of the cleaned surface to determine if a continuous or a broken film would be obtained. Broken films are considered to indicate nonuniform cleaning.

[5]Each value is the average of 10 specimens, of which five were cut from each of two 6-inch-wide lap-joint panels.

[6]Joint failures were examined and estimates made of the percentage of adhesion-to-metal failure (Ad.), of cohesion failure in the direct-bonding adhesive (Co.), of cohesion failure in the priming adhesive (P.c.), of adhesion failure between secondary adhesive and priming adhesive (P.s.) and of no or low contact between adhesive coatings on joining surfaces (N.c.).

[7]Numbers indicate series run on different days with the same adhesive process. As a part of each series, a set of specimens was prepared with metal cleaned by method E (1) as a control. Individual-series control values are indicated by these same numbers.

Table 2.--Comparison of shear strengths of lap shear specimens when clad 24S-T3 aluminum-alloy sheets were cleaned by various methods and when cleaned by the sulfuric acid-sodium dichromate process E (1)

Cleaning method[1]	Percentage of control strength obtained[2]			
	Bonding process A	Bonding process B	Bonding process C	Bonding process D
A. Benzene wash, no other treatment...	48	68	93	71
B. Abrasion cleaning				
(1) Sandblasting....................	72	80	....	......
(2) Aluminum wool....................	67	65	91	98
(3) Iron-free abrasive cloth........	73	66	82	97
C. Solvent cleaning				
(1) Five percent solution of adhesive in solvent...............	48	37	80	69
(2) Vapor degreasing................	55	70	102	52
D. Alkaline cleaning				
(1) Borax powder....................	67	70	64	85
(2) Sodium metasilicate.............	53	102	98	89
(3) Detergent cleaner I.............	31	77	90	75
(4) Alkaline cleaner J..............	13	1	21	4
(5) Sodium hydroxide................	40	8	65	63
(6) Soap K, Navy Specification C-152	21	88	77	102
E. Acid cleaning				
(1) Sulfuric acid-sodium dichromate.	100	100	100	100
(2) Chromic acid....................	50	75	91	62
(3) Phosphoric acid.................	72	81	98	96
(4) Phosphoric and chromic acid.....	41	92	66	53
(5) Deoxidizing cleaner L...........	82	88	74	81
(6) Hydrofluosilicic acid...........	83	94	77	69
F. Electrolytic cleaning.............	47	48	64	102
G. Combinations of cleaning				
(1) D (1) (borax), D (2) (sodium metasilicate), and E (2) (chromic acid)..........	90	82	100	98
(2) D (2) (sodium metasilicate) and E (2) (chromic acid)..........	92	72	91	95
(3) D (3) (detergent solution I) and E (2) (chromic acid)......	93	82	88	97

[1]The metal surfaces were washed with benzene before being cleaned with each of the other cleaning methods. The solution temperatures and concentrations, and the procedures involved in each of the cleaning methods, are described in the text of the report. It should be noted that both concentration and temperature variations between different solutions of one type make direct comparison of components inadvisable.

[2]In this table, control strength is the average strength of joints prepared at the same time and with the same bonding processes to clad 24S-T3 sheets cleaned by method E (1) (sulfuric acid and sodium dichromate).

Table 3.--Comparison of shear strengths of lap shear specimens when clad 24S-T3 aluminum-alloy sheets were cleaned by various methods and when cleaned by a simple washing in benzene (Process A)

Cleaning method[1]	Percentage of control strength obtained[2]			
	Bonding process A	Bonding process B	Bonding process C	Bonding process D
A. Benzene wash, no other treatment	100	100	100	100
B. Abrasion cleaning				
(1) Sandblasting	151	117	....	....
(2) Aluminum wool	139	94	90	125
(3) Iron-free abrasive cloth	152	96	88	124
C. Solvent cleaning				
(1) Five percent solution of adhesive in solvent	108	53	87	88
(2) Vapor degreasing	115	99	112	64
D. Alkaline cleaning				
(1) Borax powder	142	106	70	109
(2) Sodium metasilicate	122	146	109	114
(3) Detergent cleaner I	72	109	100	93
(4) Alkaline cleaner J	29	2	21	5
(5) Sodium hydroxide	87	12	66	70
(6) Soap K, Navy Specification C-152	36	133	98	142
E. Acid cleaning				
(1) Sulfuric acid-sodium dichromate	[3]200	[3]147	[3]108	[3]128
(2) Chromic acid	109	106	102	76
(3) Phosphoric acid	155	116	110	134
(4) Phosphoric and chromic acid	93	139	77	67
(5) Deoxidizing cleaner L	183	125	74	101
(6) Hydrofluosilicic acid	187	143	90	86
F. Electrolytic cleaning	80	73	67	122
G. Combinations of cleaning				
(1) D(1) (borax), D(2) (sodium metasilicate), and E(2) chromic acid)	168	137	110	124
(2) D(2) (Sodium metasilicate), and E(2) (chromic acid)	172	119	100	125
(3) D(3)(Detergent solution I), and E(2) (chromic acid)	173	136	97	123

[1]The metal surfaces were washed with benzene before being cleaned with each of the cleaning methods. The solution temperatures and concentrations, and the procedures involved in each of the cleaning methods, are described in the text of the report. It should be noted that both concentration and temperature variations between different solutions of one type make direct comparison of components inadvisable.

[2]In this table, control strength is the average strength obtained when metal was cleaned only by a benzene washing process (method A).

[3]Based on average of all values shown in table 1 for method E(1) for that adhesive.

Table 4.--Results of strength tests of lap joints of 0.064-inch clad 24S-T3 aluminum-alloy sheets having various types of surface contamination, cleaned by each of several methods and bonded with process A

Cleaning method[1]	Surface as received[2]				Surface with oil-paraffin film[3]				Surface with silicate stain[4]			
	Average shear strength[5]	Type of failure[6]: Ad.	Type of failure[6]: Co.	Series No.[7]	Average shear strength[5]	Type of failure[6]: Ad.	Type of failure[6]: Co.	Series No.[7]	Average shear strength[5]	Type of failure[6]: Ad.	Type of failure[6]: Co.	Series No.[7]
	P.s.i.	Percent	Percent		P.s.i.	Percent	Percent		P.s.i.	Percent	Percent	
A. Benzene wash, no other treatment	1,866	62	38	12	1,958	59	41	12	332	100	0	12
B. Abrasion cleaning (2) Benzene wash and aluminum wool	2,839	22	78	13	2,506	44	56	13	2,816	37	63	13
C. Solvent cleaning (2) Benzene wash and vapor degrease	1,876	77	23	(8)	1,520	50	50	14	...	...	...	...
D. Alkaline cleaning (2) Benzene wash and sodium metasilicate	1,697	54	46	10	1,108	75	25	10	155	100	0	10
E. Acid cleaning (1) Benzene wash and sulfuric-sodium dichromate	2,960	25	75	10	2,892	13	87	10	3,082	27	73	10
	3,170	28	72	11	...	...	...	...	...	...	...	...
	3,320	30	70	12	...	...	...	...	...	...	...	...
	3,264	46	54	13	...	...	...	...	...	...	...	...
	3,030	23	77	14	...	...	...	...	...	...	...	...
H. No treatment	913	87	13	11	1,924	75	25	11	289	100	0	11

[1] The solution temperatures and concentrations and the methods involved in each of the cleaning methods are described in the text of the report.

[2] The metal sheets used in preparing these specimens were sheets as normally received with red identification lettering on one side. With the exception of the specimens prepared without treatment, both surfaces were wiped with a cloth soaked in benzene prior to further treatment by other methods. The specimens prepared without treatment were bonded directly to the surface having the lettering.

[3] The metal sheets used in preparing these specimens were treated with an oil-paraffin solution to simulate the condition of surfaces that are unusually contaminated. The surfaces were prepared by wiping the identification lettering off with a cloth soaked in benzene, dipping the sheets in a solution of 50 parts carbon tetrachloride, 10 parts petroleum paraffin, and 25 parts S.A.E. No. 10 oil (all by weight), and then allowing the film to air-dry.

[4] The metal sheets used in preparing these specimens were immersed in warm sodium metasilicate solution and allowed to air-dry without rinsing to simulate the surface condition obtained when sodium metasilicate solution is not properly rinsed from sheets being cleaned with the solution.

[5] Each value is the average of 10 specimens, of which five were cut from each of two 6-inch-wide lap-joint panels.

[6] Joint failures were examined and estimates made of the percentage of adhesion-to-metal failure (Ad.) and of cohesion failure (Co.) in the direct-bonding adhesive.

[7] Series numbers indicate runs on different days with the same adhesive process. When the same series number is given for a number of test results, it indicates that all of these results were obtained from panels prepared simultaneously on the same day. As a part of each series, a set of specimens was prepared with the sheets (as received) cleaned with sulfuric acid-sodium dichromate as a control.

[8] Because of a lack of sufficient materials to repeat the degreasing process for this part of the study, these test data for this surface condition and cleaning method were taken from data in table 1.

Table 5.--Results of strength tests of lap joints of 0.064-inch clad 24S-T3 aluminum-alloy sheets having various types of surface contamination, cleaned by each of several methods and bonded with process B

Cleaning method[1]	Surface as received[2]				Surface with oil-paraffin film[3]				Surface with silicate stain[4]			
	Average shear strength[5]	Type of failure[6]: Ad.	Type of failure[6]: Co.	Series No.[7]	Average shear strength[5]	Type of failure[6]: Ad.	Type of failure[6]: Co.	Series No.[7]	Average shear strength[5]	Type of failure[6]: Ad.	Type of failure[6]: Co.	Series No.[7]
	P.s.i.	Percent	Percent		P.s.i.	Percent	Percent		P.s.i.	Percent	Percent	
A. Benzene wash, no other treatment	1,996	94	6	9	1,954	83	17	9	402	100	0	8
B. Abrasion cleaning (2) Benzene wash and aluminum wool	2,456	63	37	10	2,030	57	43	10	2,626	63	37	10
C. Solvent cleaning (2) Benzene wash and vapor degrease	2,020	79	21	11	1,200	94	6	13	....	....	....	......
D. Alkaline cleaning (2) Benzene wash and sodium metasilicate	2,668	65	35	12	2,714	67	33	12	267	100	0	12
E. Acid cleaning (1) Benzene wash and sulfuric-sodium dichromate	2,536	74	26	8	2,592	67	33	12	2,618	69	31	12
	2,762	70	30	9	....	....	....	......	....	....	....	......
	2,538	55	45	10	....	....	....	......	....	....	....	......
	2,782	50	50	11	....	....	....	......	....	....	....	......
	2,706	69	31	12	....	....	....	......	....	....	....	......
	3,082	63	37	13	....	....	....	......	....	....	....	......
H. No treatment	1,954	86	14	8	1,268	30	70	8	290	100	0	8

[1] The solution temperatures and concentrations and the methods involved in each of the cleaning methods are described in the text of the report.

[2] The metal sheets used in preparing these specimens were sheets as normally received with red identification lettering on one side. With the exception of the specimens prepared without treatment, both surfaces were wiped with a cloth soaked in benzene prior to further treatment by other methods. The specimens prepared without treatment were bonded directly to the surface having the lettering.

[3] The metal sheets used in preparing these specimens were treated with an oil-paraffin solution to simulate the condition of surfaces that are unusually contaminated. The surfaces were prepared by wiping the identification lettering off with a cloth soaked in benzene, dipping the sheets in a solution of 50 parts carbon tetrachloride, 10 parts petroleum paraffin, and 25 parts S.A.E. No. 10 oil (all by weight), and then allowing the film to air-dry.

[4] The metal sheets used in preparing these specimens were immersed in warm sodium metasilicate solution and allowed to air-dry without rinsing to simulate the surface condition obtained when sodium metasilicate solution is not properly rinsed from sheets being cleaned with the solution.

[5] Each value is the average of 10 specimens, of which five were cut from each of two 6-inch-wide lap-joint panels.

[6] Joint failures were examined and estimates made of the percentage of adhesion-to-metal failure (Ad.) and of cohesion failure (Co.) in the direct-bonding adhesive.

[7] Series numbers indicate runs on different days with the same adhesive process. When the same series number is given for a number of test results, it indicates that all of these results were obtained from panels prepared simultaneously on the same day. As a part of each series, a set of specimens was prepared with the sheets (as received) cleaned with sulfuric acid-sodium dichromate as a control.

Table 6.--Results of strength tests of lap joints of 0.064-inch clad 24S-T3 aluminum-alloy sheets having various types of surface contamination, cleaned by each of several methods and bonded with process G

Cleaning method[1]	Surface as received[2]					Surface with oil-paraffin film[3]					Surface with silicate stain[4]				
	Average shear strength[5]	Type of failure[6]			Series No.[7]	Average shear strength[5]	Type of failure[6]			Series No.[7]	Average shear strength[5]	Type of failure[6]			Series No.[7]
		Ad.	Co.	N.c.			Ad.	Co.	N.c.			Ad.	Co.	N.c.	
	P.s.i.	Percent	Percent	Percent		P.s.i.	Percent	Percent	Percent		P.s.i.	Percent	Percent	Percent	
A. Benzene wash, no other treatment	2,624	50	45	5	8	2,240	52	40	8	9	665	100	0	0	10
B. Abrasion cleaning (2) Benzene wash and aluminum wool	2,235	94	0	6	8	1,656	83	2	15	9	1,910	93	0	7	10
C. Solvent cleaning (2) Benzene wash and vapor degrease	2,768	26	72	2	(8)	1,622	100	0	0	11	....	....	....	....	....
D. Alkaline cleaning (2) Benzene wash and sodium metasilicate	2,734	4	93	3	8	2,470	0	85	15	9	773	96	0	4	12
E. Acid cleaning (1) Benzene wash and sulfuric-sodium dichromate	2,748	11	78	11	8	2,908	20	76	4	11	2,312	97	0	3	10
	2,490	3	89	8	9	....	....	....	....	....	....	....	....	....	....
	2,500	8	81	11	10	....	....	....	....	....	....	....	....	....	....
	2,894	45	50	5	11	....	....	....	....	....	....	....	....	....	....
	2,798	11	86	3	12	....	....	....	....	....	....	....	....	....	....
H. No treatment	2,380	57	39	4	8	243	100	0	0	9	270	100	0	0	10

[1]The solution temperatures and concentrations and the methods involved in each of the cleaning methods are described in the text of the report.

[2]The metal sheets used in preparing these specimens were sheets as normally received with red identification lettering on one side. With the exception of the specimens prepared without treatment, both surfaces were wiped with a cloth soaked in benzene prior to further treatment by other methods. The specimens prepared without treatment were bonded directly to the surface having the lettering.

[3]The metal sheets used in preparing these specimens were treated with an oil-paraffin solution to simulate the condition of surfaces that are unusually contaminated. The surfaces were prepared by wiping the identification lettering off with a cloth soaked in benzene, dipping the sheets in a solution of 50 parts carbon tetrachloride, 10 parts petroleum paraffin, and 25 parts S.A.E. No. 10 oil (all by weight), and then allowing the film to air-dry.

[4]The metal sheets used in preparing these specimens were immersed in warm sodium metasilicate solution and allowed to air-dry without rinsing to simulate the surface condition obtained when sodium metasilicate solution is not properly rinsed from sheets being cleaned with the solution.

[5]Each value is the average of 10 specimens, of which five were cut from each of two 6-inch-wide lap-joint panels.

[6]Joint failures were examined and estimates made of the percentage of adhesion-to-metal failure (Ad.), cohesion failure in the direct bonding adhesive (Co.), and no or low contact between adhesive coatings on joining surfaces (N.c.).

[7]Series numbers indicate runs on different days with the same adhesive process. When the same series number is given for a number of test results, it indicates that all of these results were obtained from panels prepared simultaneously on the same day. As a part of each series, a set of specimens was prepared with the sheets (as received) cleaned with sulfuric acid-sodium dichromate as a control.

[8]Because of a lack of sufficient materials to repeat the degreasing process for this part of the study, these test data for this surface condition and cleaning method were taken from data in table 1.

Figure 1.--Test machine and grips used in applying tension loading on bonded lap-joint specimens of 0.064-inch clad 24S-T3 aluminum-alloy sheets.

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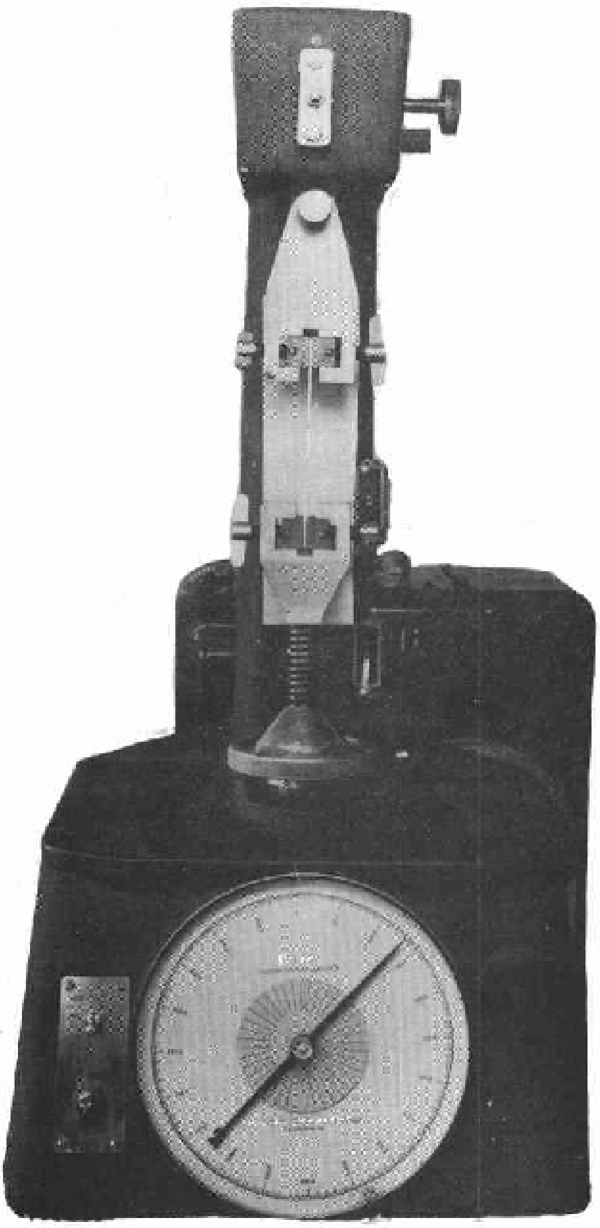

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