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Report on

Research of the Weldability of Iron Alloys

(Comparison of V-Notched and Tee-Bend Test Specimens)

by

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BELLEVUE, D. C.

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NAVY DEPARTMENT

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Research of the Weldability of Iron Alloys

(Comparison of V-Notched and Tee-Bend Test Specimens).

NAVAL RESEARCH LABORATORY
ANACOSTIA STATION
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Table of Contents

Appendices

ABSTRACT

In order to be able to judge the full value of the V-notched bar test specimens described and proposed in Naval Research Laboratory Report No. M-1544 of 21 June 1939, it was felt that a comparison of the results of these specimens with some type of practical test was essential. It was considered logical, as a preliminary survey, to compare the V-notched bar test values with the results of the Tee-bend test for determining the weldability of high tensile steel. This test is that used by the Bureau of Construction and Repair. The present investigation considers the results obtained from comparative tests using the same welding technique with full automatic control in preparation of V-notched and Tee-bend test specimens for a series of sixteen different low carbon and alloy steels. A very definite correlation exists between the results of the V-notched bar and the Tee-bend test values. In general, it may be said that except for laminated plate material that high and ductile V-notched bar values will predict good Tee-bend behavior. Conversely, brittle V-notched bar behavior either in plate material or in bead welds will predict failure in the Tee-bend test.

In the present status of testing for weldability, it is strongly urged that future tests include both the V-notched and Tee-bend test specimens.

INTRODUCTION

(a) Authorization

1. This problem was authorized by Bureau of Engineering letter JJ46-1/L5 (4-2-Ds) of 4 April 1935.

2. A report covering part of the work was submitted under Naval Research Laboratory Report No. M-1544 of 21 June 1939.

(b) Statement of Problem

3. In order to be able to judge the full value of the V-notched bar test specimens described and proposed in Naval Research Laboratory Report No. M-1544 of 21 June 1939, it was felt that a comparison of the results of these specimens with some type of practical test was essential. It was felt logical, as a preliminary survey, to compare the V-notched bar test values with the results of the Tee-bend test for determining the weldability of high tensile steel. This test is that used by the Bureau of Construction and Repair.

4. The present investigation considers the results obtained from comparative tests using the same welding technique in preparation of V-notched and Tee-bend test specimens for a series of different low carbon and alloy steels.

(c) Known Facts Bearing on the Problem (Theoretical Considerations)

5. From the summary and conclusions given in Naval Research Laboratory Report No. M-1544, we have -

(a) The use of a single and double width Charpy V-notched test specimen of a welding steel in as-rolled condition may be used to indicate the degree of notch sensitivity of a welding steel.

(b) The use of a single and double width Charpy V-notched test specimen of a welding steel with the apex of the notch tangent to the heat affected zone under a bead weld may be used to indicate the degree of notch sensitivity of the welding steel after being subjected to a weld thermal cycle.

(c) By comparing the notched bar value of plate material with that of the bead weld notched bar, an indication is obtained of the effect of weld heat treatment on the notch sensitivity.

6. By reason of the geometry of the test specimen and the method of test a concentration of stress is produced at the apex of the notch. Laurent and Popoff have shown this concentration to be 4.78 times the average stress.

7. The Tee-bend test for determining the weldability of high tensile steel has been used extensively in the work of the Bureau of Construction and Repair. The vast amount of data indicates its usefulness as a summary test of the base material as well as the material in the welded condition. Due to the geometry of the test specimen, a concentration of stress is obtained at the toe of the weld. Coker has shown this stress concentration to be some less than twice the average stress provided no undercutting is present.

8. Since a concentration of stress is produced in both the Charpy V-notched bar and Tee-bend test specimens, the comparison of these two types of test specimens seemed a logical method of attack in evaluation of their significance in connection with weldability. Identical welding techniques may be used in the preparation of both test specimens.

MATERIAL UNDER TEST

9. Eight steels from the series of laboratory and commercial steels, which were used in the previous studies of this problem, were used as material for the present phase of this investigation. Seven steels furnished by the Bureau of Construction and Repair in connection with the weld quench tests reported in our letter to the Chief of the Bureau of Construction and Repair dated 14 June 1938, were also used in this study. The chemical analyses of the plate material appear in Table 1.

10. No. 78 Airco, Grade EA, Class 2, heavy coated electrodes 3/16" in diameter, were used as the standard electrode in this welding study.

METHODS OF TEST

11. Full automatic control of welding conditions was maintained in all tests.

12. Single bead welds were deposited transverse to the direction of rolling on 6 x 7 x 1/2" plates in the as-rolled condition. The electrode was used with reversed polarity at 175 amperes, 25 volts, and a speed of travel of 6 inches per minute. An approach plate was used in order to make a greater portion of the test plate available for investigation. Five standard (.394" x .394" x 2.165") and two double width (.394" x .788" x 2.165") V-notched bar bead weld specimens were prepared. After these were ground and etched the location of the V-notch was determined by using a micrometer for measurement. The apex of the standard V-notch was machined tangent to the fusion line as in Plate 1. Five standard and two double width specimens were also made for each plate material tested.

13. Tee-bend test specimens were prepared using a welding technique identical to that used in preparing the single bead welds

described in paragraph 12. Since the material available was limited, it was necessary to use plates 6 x 12 x 1/2" and 6 x 3 x 1/2" for the Tee. Welding was done in the flat position with an approach plate and full automatic control. Two Tee-bend specimens were made from each test joint.

14. The V-notched bar specimens were broken in an Amsler pendulum type machine at a temperature between 70 and 75°F.

15. The Tee-bend specimens were all tested at the National Bureau of Standards under the direction of Mr. Ellinger. In this preliminary study this was an advantage since the special jigs required for this test were not available at the Laboratory. Mr. Ellinger's interest in this work is heartily appreciated.

DATA OBTAINED

16. Notched bar test values for the plate material and bead weld specimens are presented in Table II.

17. Tee-bend test results are presented in Table III.

18. Plates 2 to 17 compare the V-notched bars and the Tee-bend for this series of materials.

CONCLUSIONS AND RECOMMENDATIONS

(a) Facts Established

19. A very definite correlation exists between the results of the V-notched bar and the Tee-bend test values.

20. The V-notched bar test gives an indication of the relative toughness of the plate in the as-rolled and the weld heat-treated condition. The results of the Tee-bend test may be predicted from these results.

21. The Tee-bend test serves as a summary test and indicates the relative merit of any steel when used in a weld joint of the tee type.

(b) Collateral Facts with Recommended Application

22. Several half width Tee-bend specimens were tested. Results were as follows:

Steel No.	Angle at Maximum Load	Load
1	43°	2108 pounds
9	26	2616
11	58	3480
20	66-1/2	3480
29	68	2982
30	51	3728
31	30	4776
32	65	2980

It is to be noted that in all cases except steel No. 29 that the angle at maximum load is greater than that obtained in the standard width specimens. In all cases except steel numbers 1 and 20 the maximum load was equal to or greater than one-half of that of a standard width specimen. Tests have not been sufficient in number to make any definite conclusions at this time; however, it is felt that very little additional information is available from the half-width Tee-bend specimen.

23. Two additional test specimens were prepared from steel No. 39. These consisted of Tee-bend specimens machined from 3" x 3" stock. The fillet was machined so that the specimen had the same geometrical shape and size as a welded test specimen. In comparing this type of specimen with the welded specimen no difference was noted in the angle at maximum load. The maximum load, however, was slightly lower with a value of 4904 pounds as compared to 5115 pounds.

24. The question of stress concentration at the toe of the weld might be well investigated by using a photoelastic model. Hence a bakelite model of the Tee-bend section was constructed and stress patterns were photographed. As was expected, stress concentration occurs at the toe of the weld (see Plate 18). This concentration as shown by Coker will be less than twice the average stress.

(c) Discussion of Data

25. In general, it may be said that except for laminated plate material, that high and ductile V-notched bar values will predict good Tee-bend behavior. Conversely, brittle V-notched bar behavior either in plate material or in bead welds will predict failure in the Tee-bend test.

26. Two steels, numbers 29 and 32, give satisfactory performance in both the V-notched bar and Tee-bend test in the as-rolled condition. Steel No. 39 tested only in the full annealed condition also performs satisfactorily in these tests. These three steels may be classed as Grade 1 steels.

27. Steels numbers 145B, 146C, 11 and 150B do not come up to the steels of Grade 1 in performance. They are mediocre in behavior.

28. Steels numbers 1, 9 and 144B are not uniform in structure, tests showing the presence of a laminated structure in the plate material. These show high V-notched bar values, and indicate fair performance in as far as this test value is concerned. The tearing action across the lamination, however, has a tendency to absorb more energy than would occur in the case of a more homogeneous steel. The tearing break such as shown in Plate 3 is not acceptable and the V-notched bar test value is not a true measure of the properties of the steel.

29. Steels numbers 20, 30, 31, 147C, 148B, and 149B all show a sharp break in the plate material in the Tee-bend test. V-notched

bar values on the plate material are also brittle and the fracture granular. Weld heat-treatment improves the properties of all these steels.

SUMMARY AND CONCLUSIONS

30. A very definite correlation exists between the results of the V-notched bar and the Tee-bend test values.

31. The advantages of the Tee-bend test for study of weldability are:

(a) Test result indicates a summary of the behavior of a weld joint; both quality of the parent metal and weld behavior are considered.

(b) Test specimen is easily and cheaply prepared.

(c) Test sample is of such a size that local conditions do not produce erratic results.

(d) The presence of laminations in the plate material are easily shown by the type of fracture.

32. The disadvantages of the V-notched test for study of weldability are:

(a) The number of test specimens are of a necessity increased since tests are made under four different conditions.

(b) Test specimen is more expensive to prepare than the Tee-bend test specimen.

(c) Test values for laminated plate, because of the tearing type of fracture, may be high. However, type of fracture will indicate the presence of a laminated condition.

(d) Because of the small size of test specimen and the spread of results which occur in some steels, the number of tests for an average must be increased.

33. The disadvantages of the Tee-bend test for study of weldability are:

(a) Welding technique for any particular set of tests is more or less fixed.

(b) No numerical value is obtained which will distinguish between a failure due to plate quality and a failure due to weld sensitivity.

(c) In a poor quality steel little indication is given as to the effect of weld heat-treatment.

34. The advantages of the V-notched test specimen for study of weldability are:

(a) Welding technique may be varied to suit practical requirements.

(b) Test results indicate whether cause of failure is due to poor quality plate or sensitivity to weld heat-treatment.

(c) Properties of the plate in the as-received and after weld heat-treatment are obtained.

(d) Test results of the V-notched specimens may be used to predict behavior of the material on the Tee-bend test.

35. In both the V-notched bar and Tee-bend test specimen in their present state of development the effects of a single bead weld are studied. The effect of multiple beads and full joints are not considered. The V-notched test specimen may be most readily adapted to this study.

36. In the present status of testing for weldability it is strongly urged that future tests include both the V-notched and Tee-bend test specimens. The use of a V-notched test specimen on plate material before welding may indicate whether the quality of the plate material is such as to justify further testing.

Table I

Chemical Analyses for Steels Investigated.

Steel No.	C	Mn	Si	Ni	Cu	Mo	Cr	V	S	P
1	0.17	0.41	0.17						0.032	0.007
9	0.24	0.48	0.23						0.027	0.011
11	0.29	1.06	0.25						0.017	0.002
20	0.24	0.46	0.001						0.051	0.022
29	0.028	0.19		2.08					0.044	0.002
30	0.09	0.72	0.047	0.96	1.34	0.11			0.023	0.050
31	0.24	0.74	0.012	0.76	1.48	0.16			-	-
32	0.12	0.75	0.48				0.34		0.023	0.014
39	0.21	0.46	0.25						0.026	0.011
144B	0.18	1.18	0.22		0.16		0.05	0.07	0.029	0.017
145B	0.08	0.76	0.15	0.27	0.10	0.44			0.028	0.011
146C	0.10	0.38	0.16	1.90	1.01				0.019	0.015
147C	0.14	0.57	0.15	1.95	1.08		0.02		0.024	0.014
148B	0.09	0.75	0.06	0.72	1.63	0.10			0.024	0.097
149B	0.09	0.56	0.17	0.59	1.04				0.023	0.112
150B	0.16	0.59	0.18	1.90	0.14	0.10			0.026	0.014

Table II

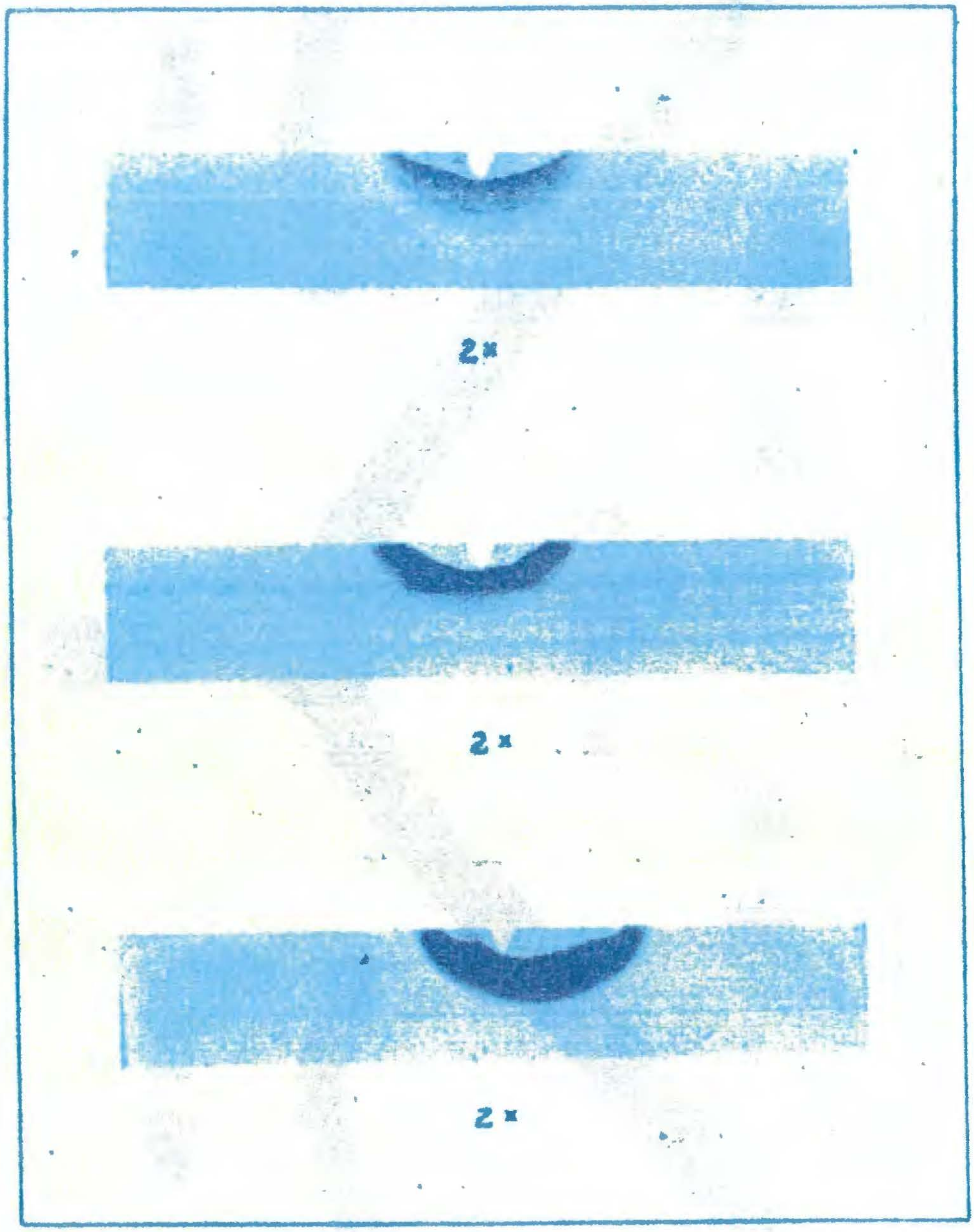
Charpy V-Notched Test Results.

Steel No.	Plate Standard	Plate Double Width	Bead Weld Standard	Bead Weld Double Width	Type of Fracture
1	55	101	44	85	Woody tearing break - some lamination.
9	41	73	35	60	Woody tearing break - laminated.
11	107	147	76	139	Plate ductile - bead weld woody.
20	39	35	48	44	Plate brittle.
29	163	+220	129	+220	All breaks ductile.
30	23	40	100	+220	Plate brittle - bead weld ductile.
31	22	39	39	72	Plate brittle.
32	121	+220	118	+220	All breaks ductile.
39	74	82	115	164	Plate not as ductile as bead weld.
144B	110	172	107	190	Woody tearing break - laminated.
145B	[illegible]	+220	177	+220	All breaks ductile.
146C	81	110	86	185	Plate not as ductile as bead weld.
147C	38	48	60	101	Plate brittle - bead weld improved.
148B	4	13	129	160	Plate extremely brittle.
149B	20	38	29	57	Plate brittle - bead weld slightly better.
150B	58	114	53	106	All breaks medium tough.

Table III

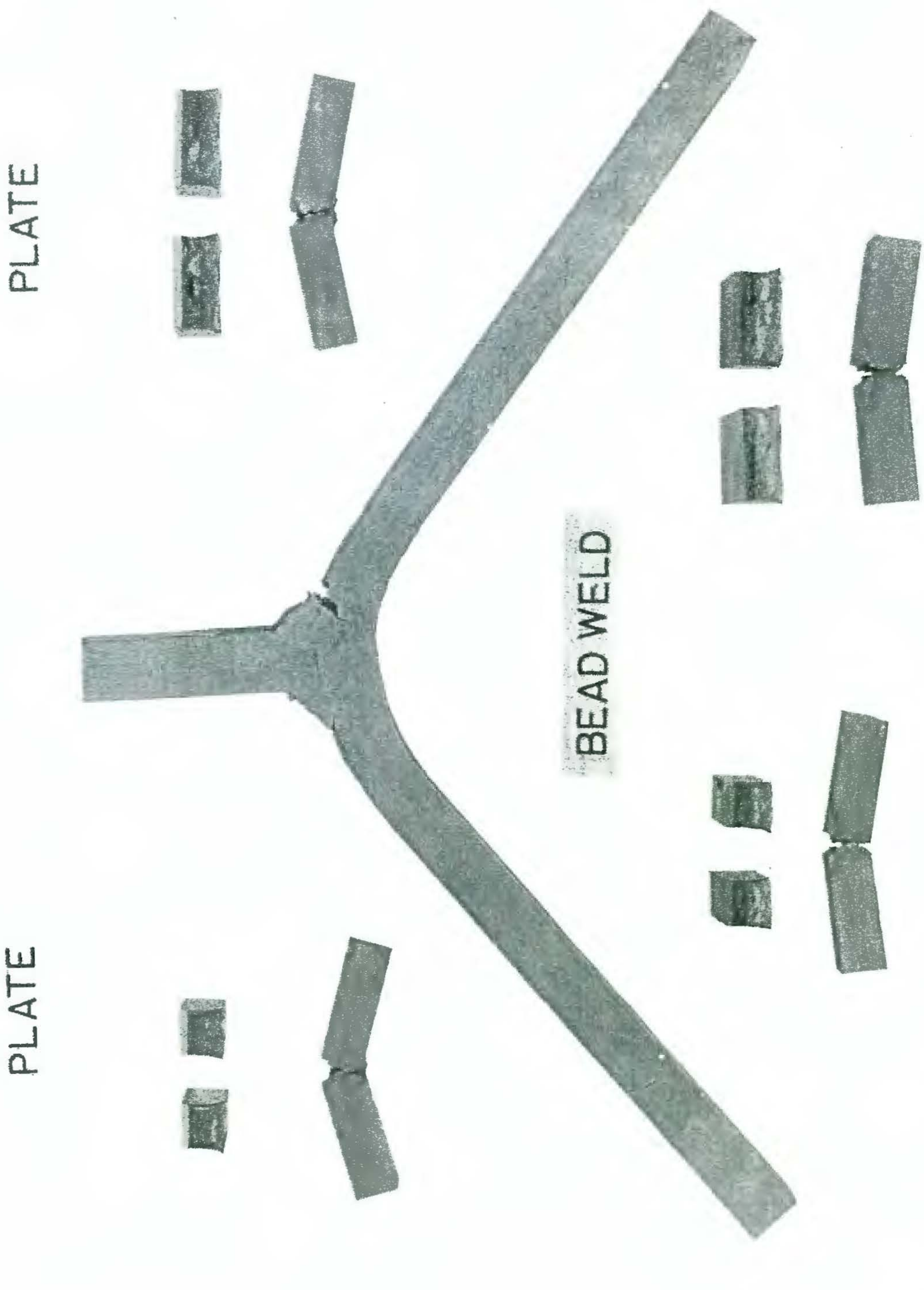
Tee-Bend Test Results.

Steel No.	Angle of Deflection at Maximum Load	Maximum Load	Type of Failure
1	37°	5142 pounds	Bond and plate (laminated).
9	16	4586	Bond and plate (laminated).
11	44	6536	Bond failure.
20	62	7252	Plate (sharp break).
29	64	5680	Slight bond.
30	48	7535	Plate (sharp break).
31	15	7950	Plate (sharp break).
32	44	5886	Slight bond.
39	72	5115	Slight bond.
144B	24	6482	Bond and plate (laminated).
145B	43	6140	Bond and plate.
146C	48	6032	Bond and plate.
147C	58	7406	Plate (sharp break).
148B	28	8274	Plate (sharp break).
149B	50	6420	Plate (sharp break).
150B	44	7088	Bond and plate.



BEAD WELD NOTCHED-BAR SPECIMENS.

Plate 1



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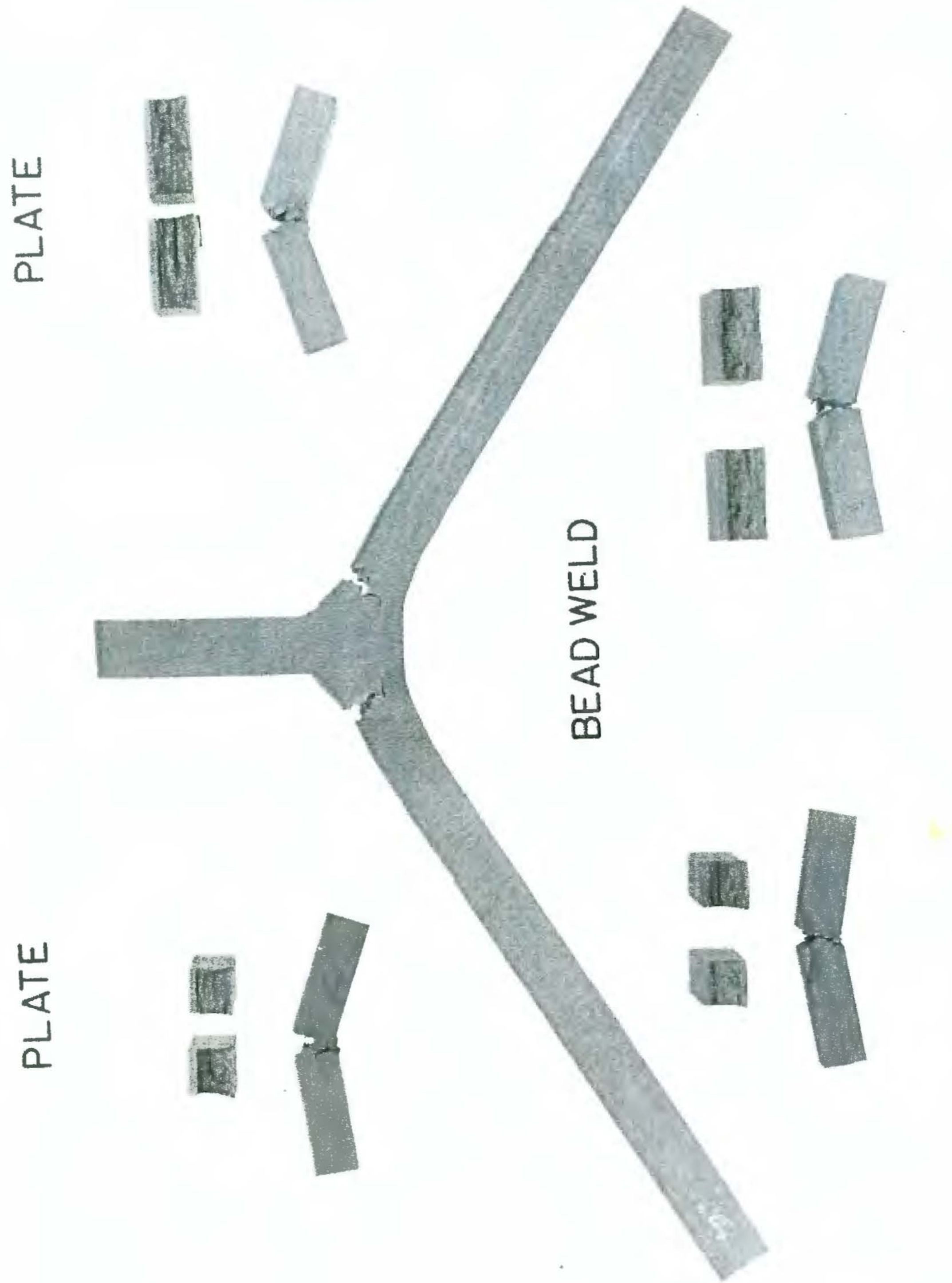

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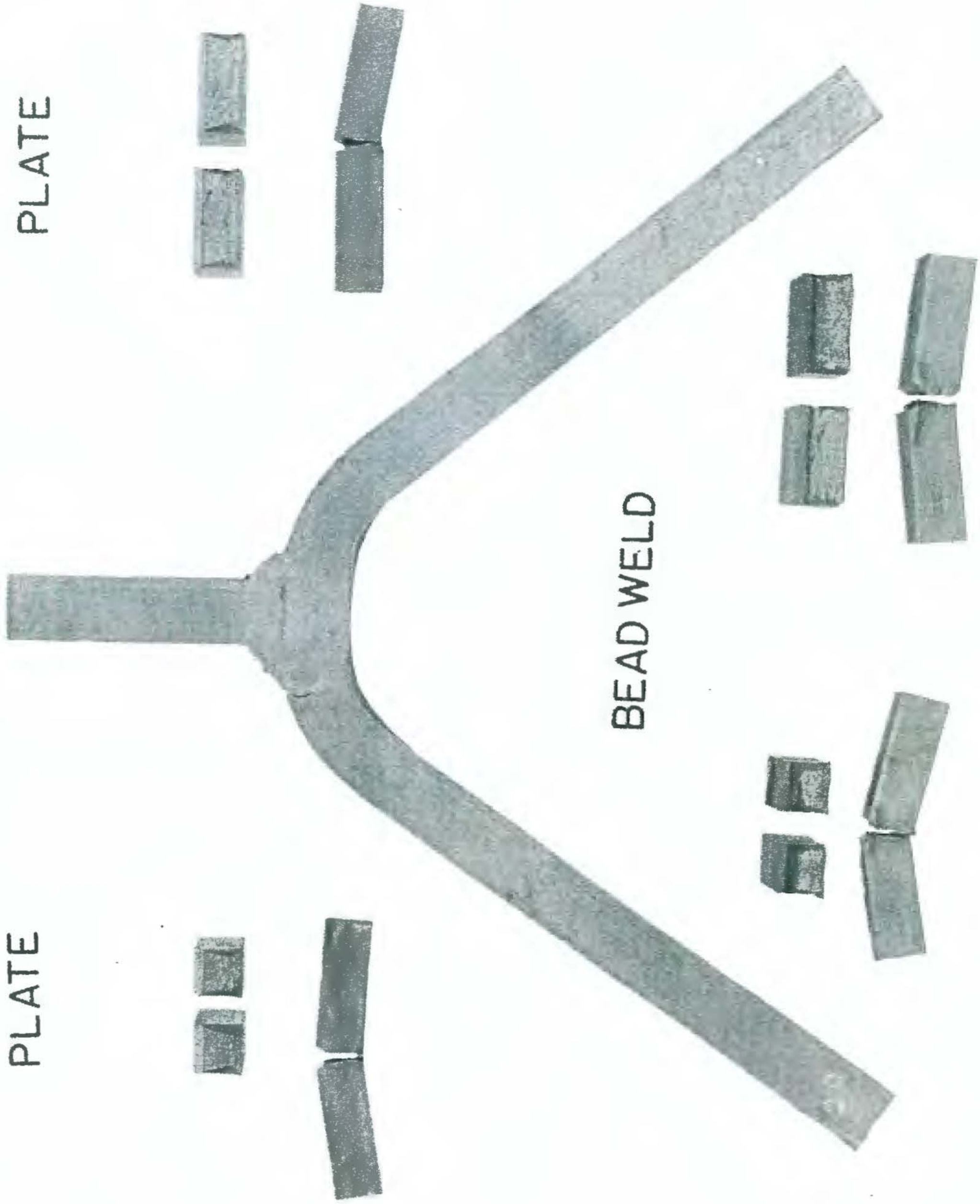

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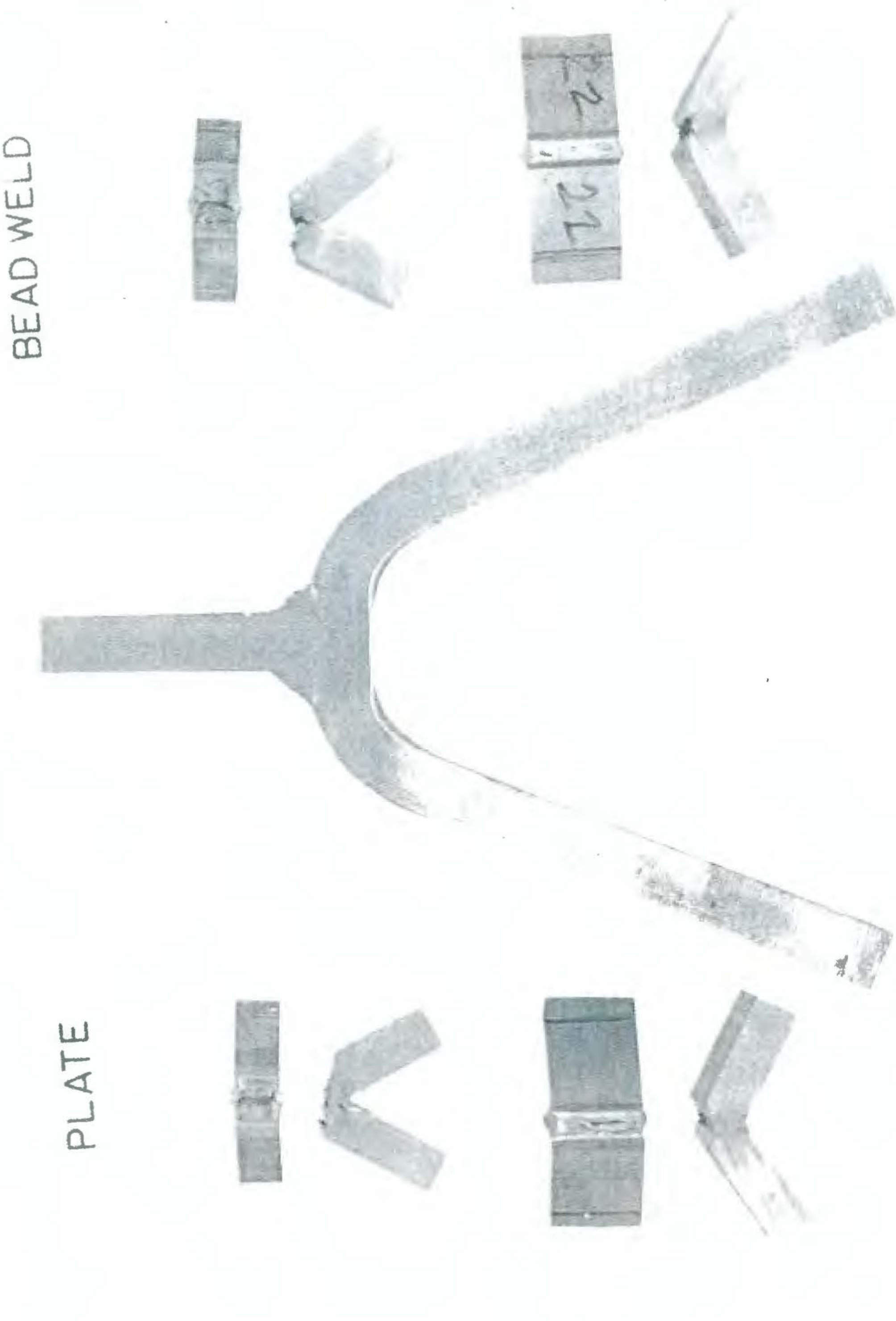

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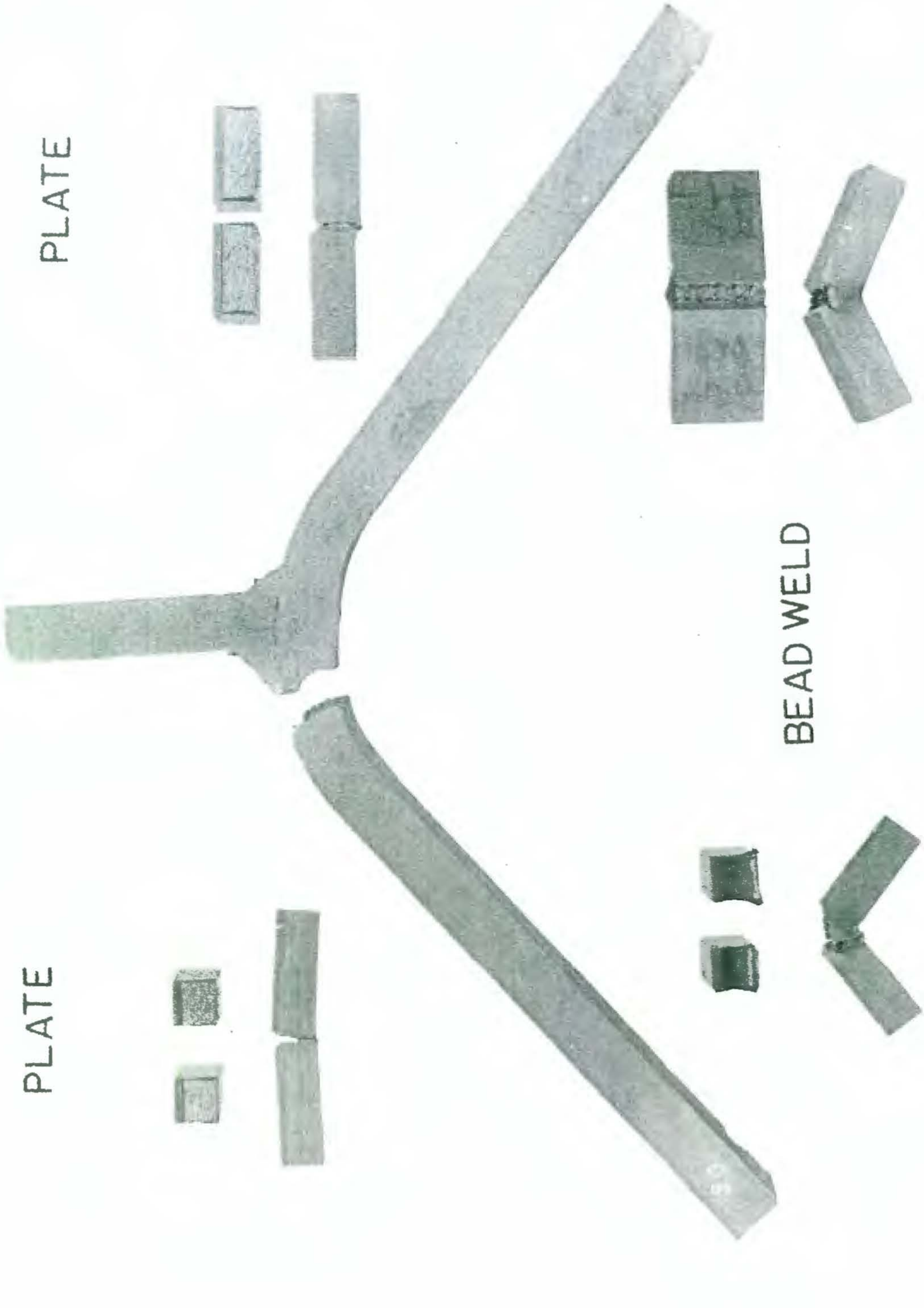

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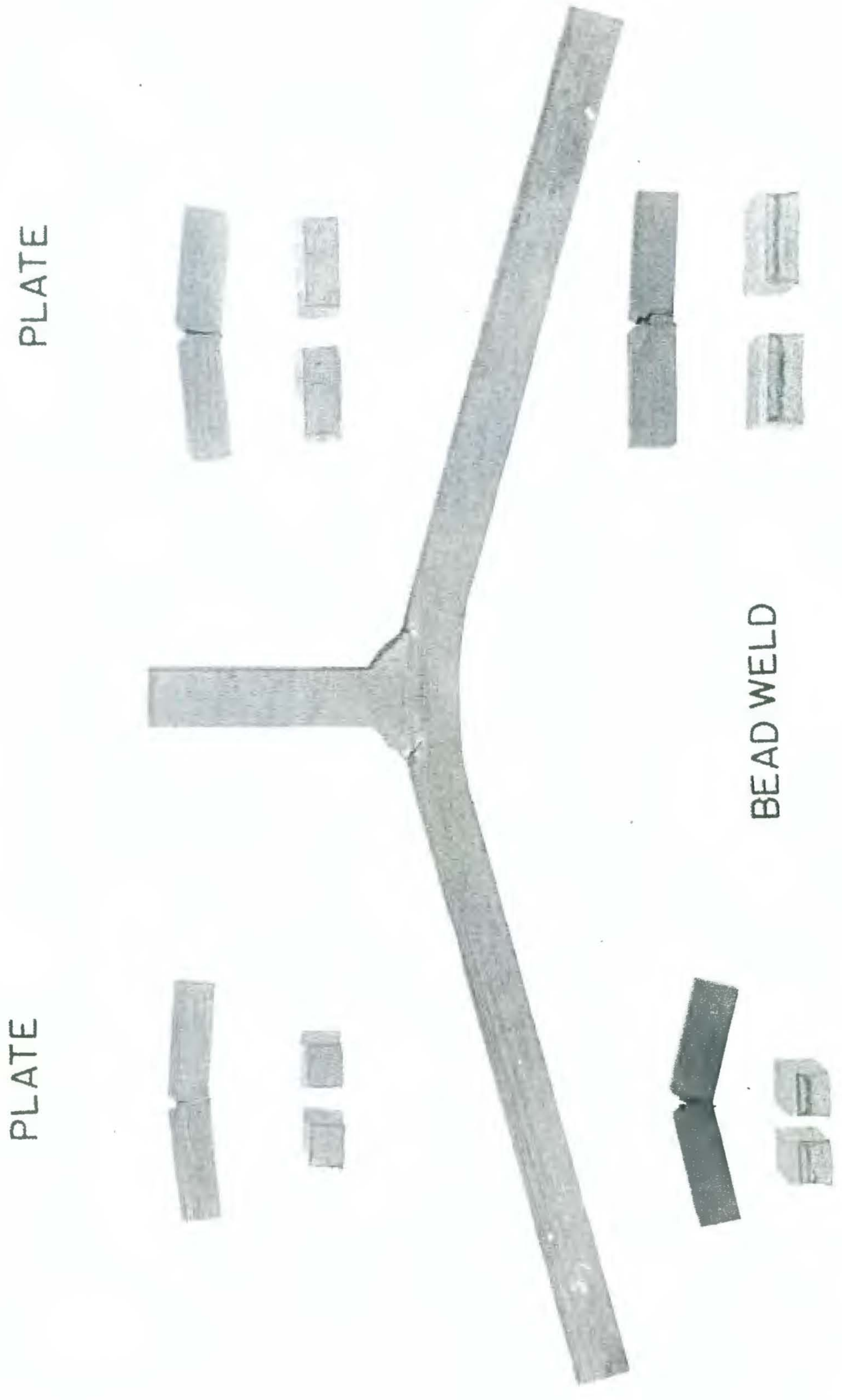

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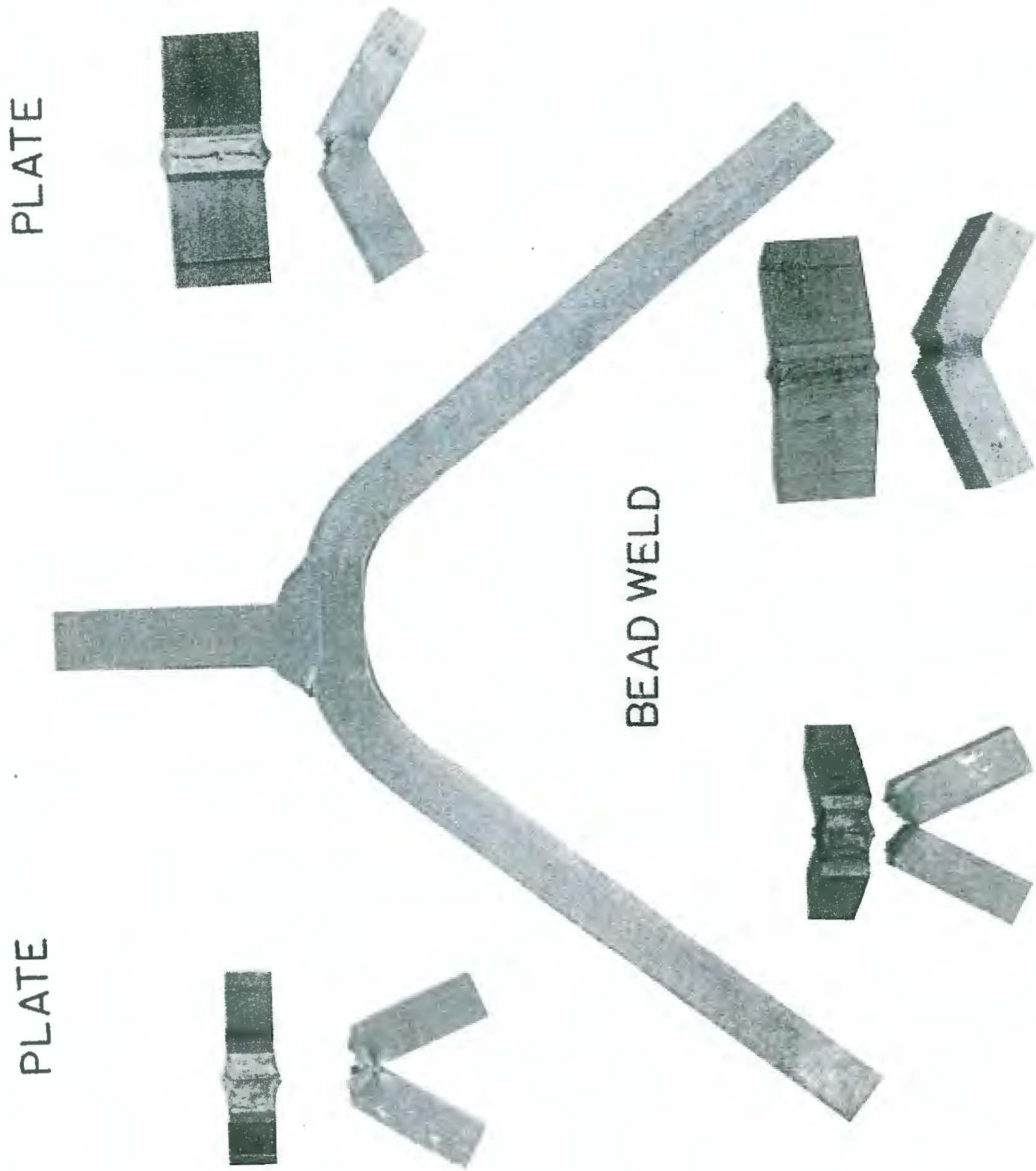

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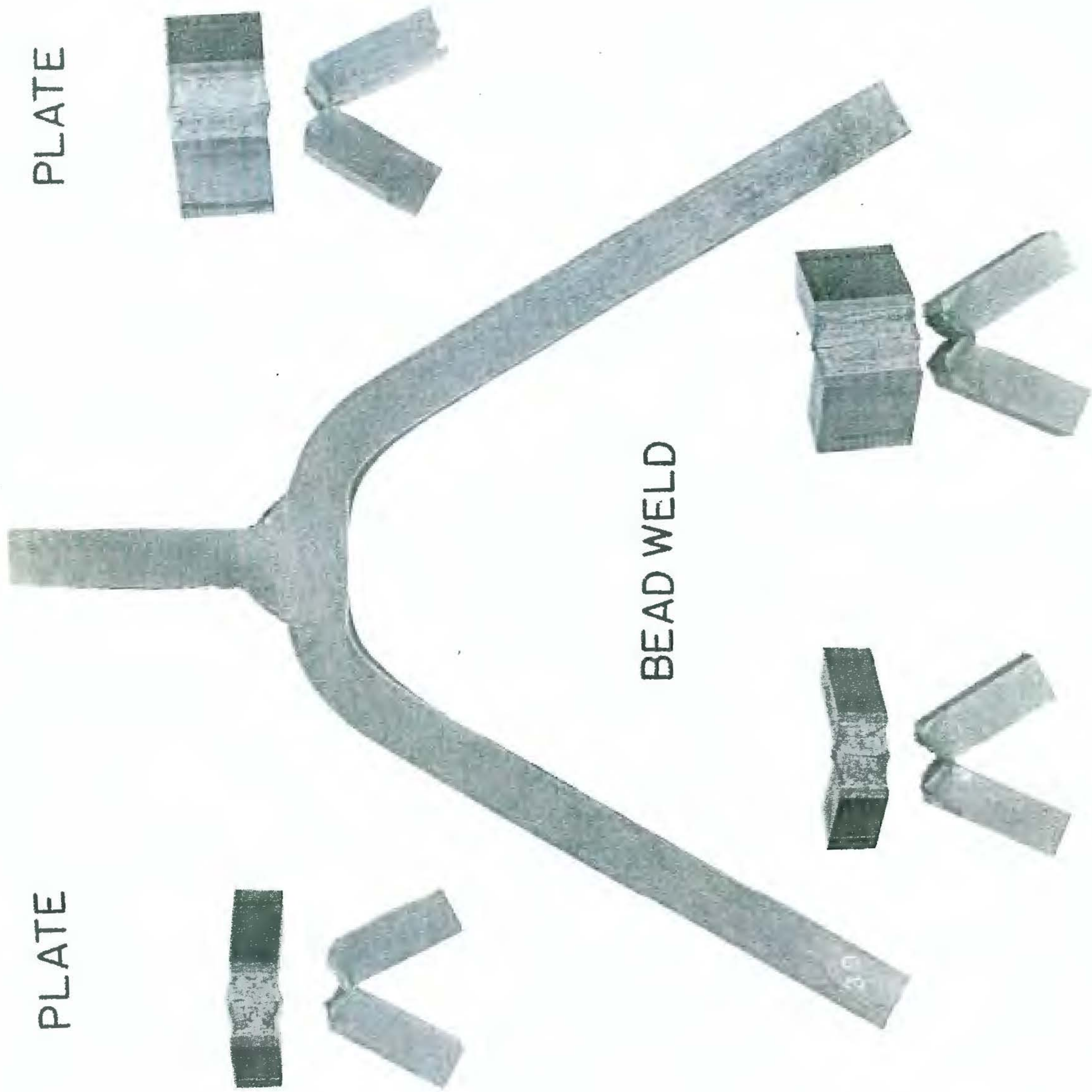

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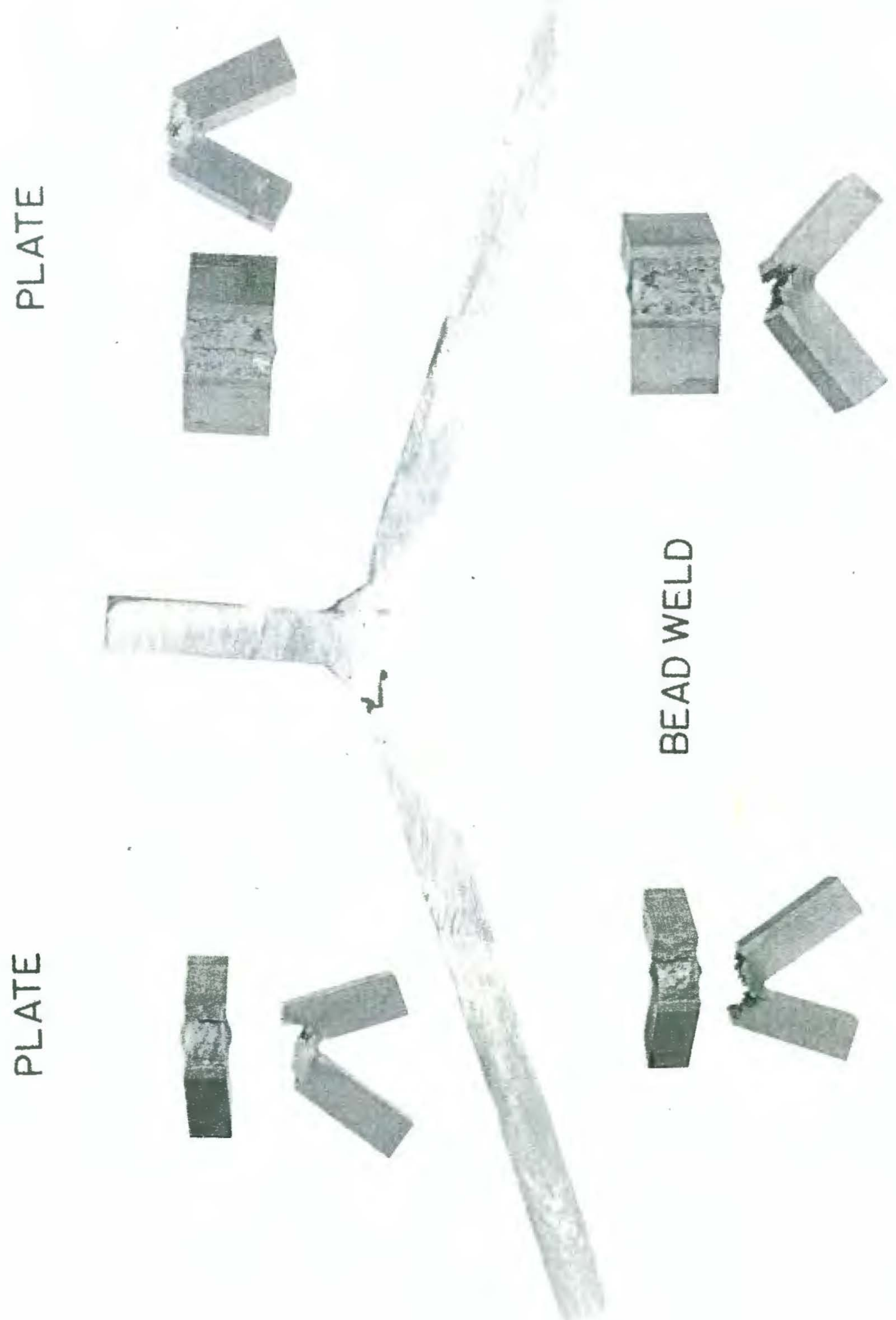

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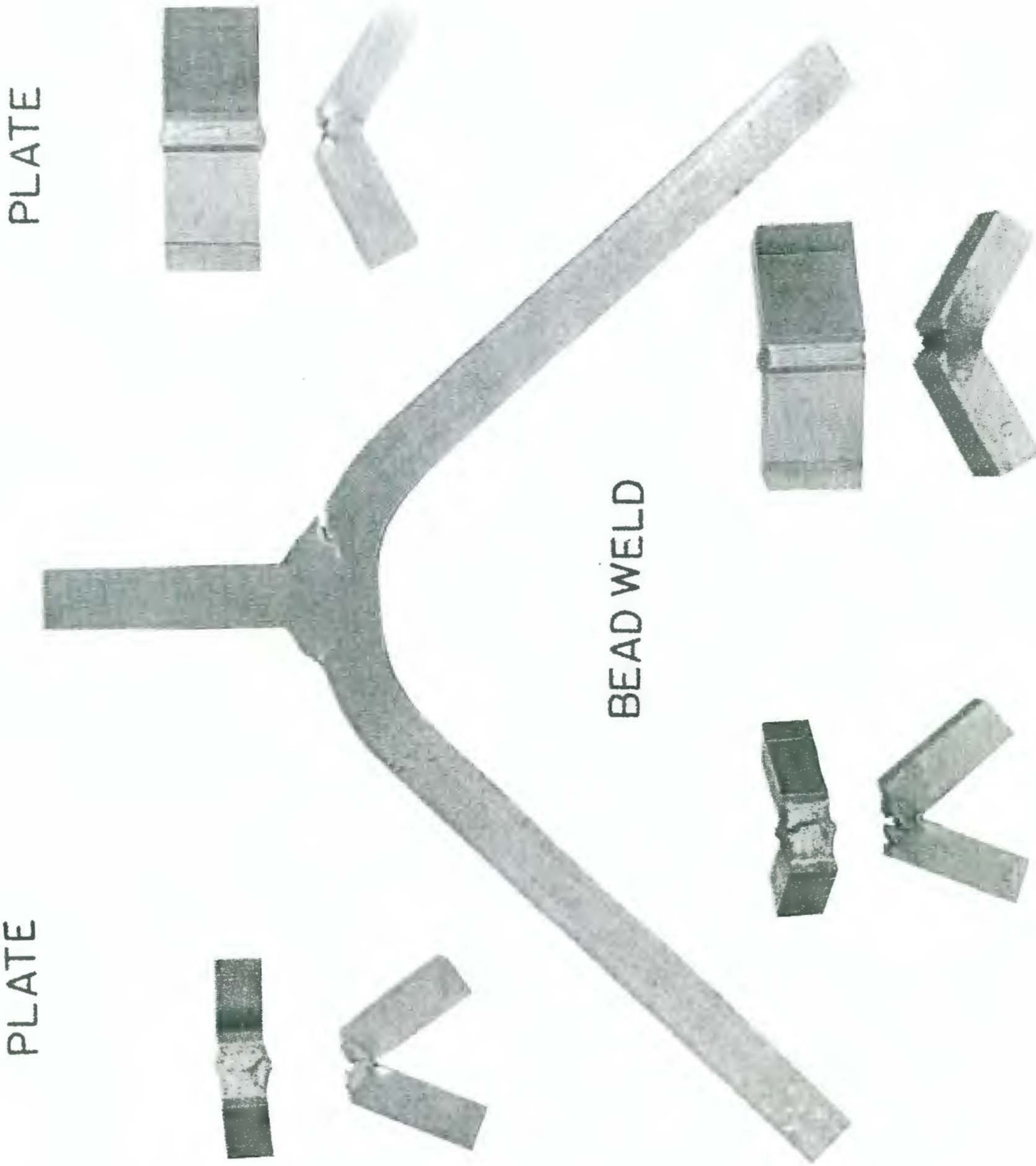

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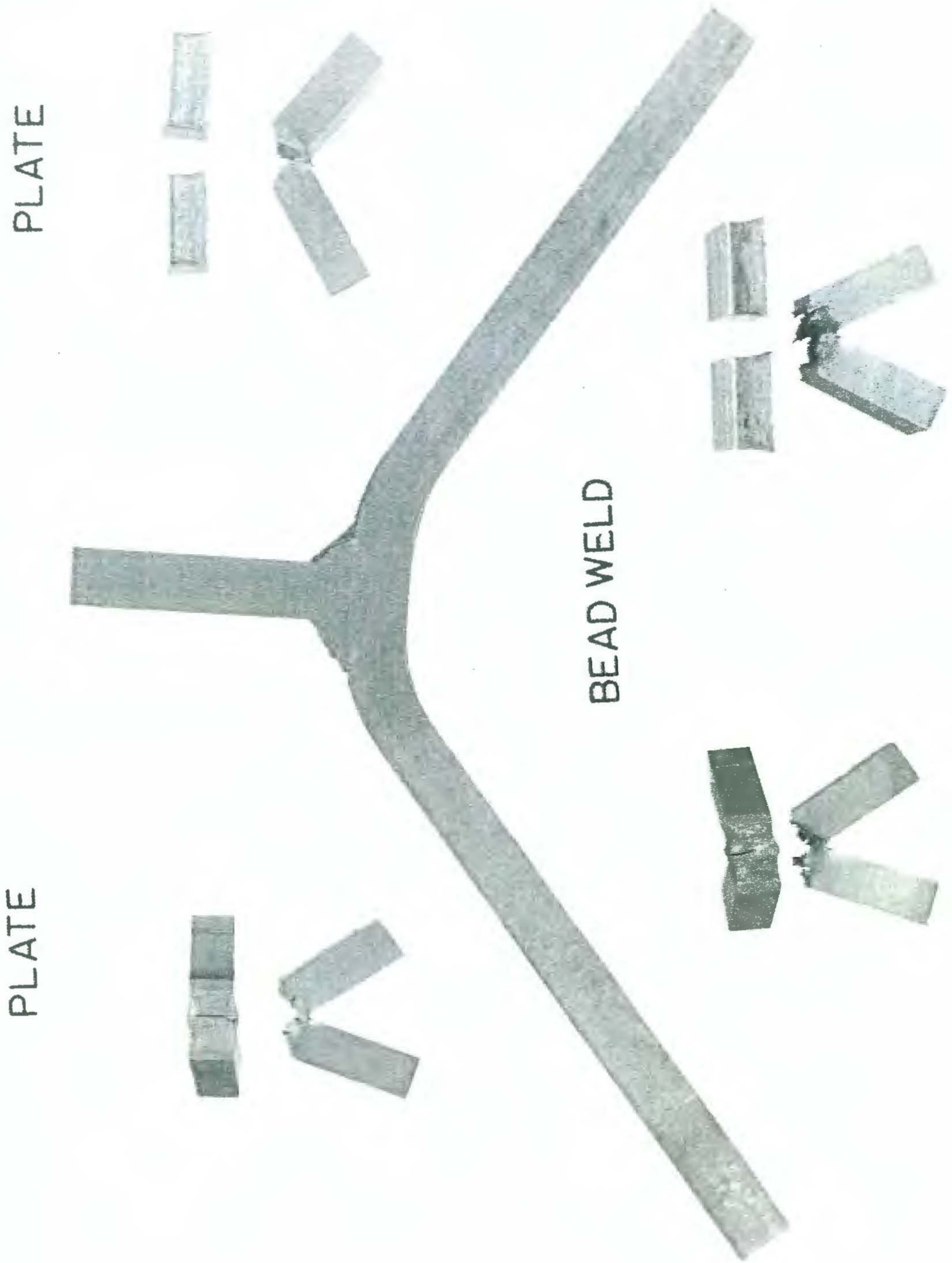

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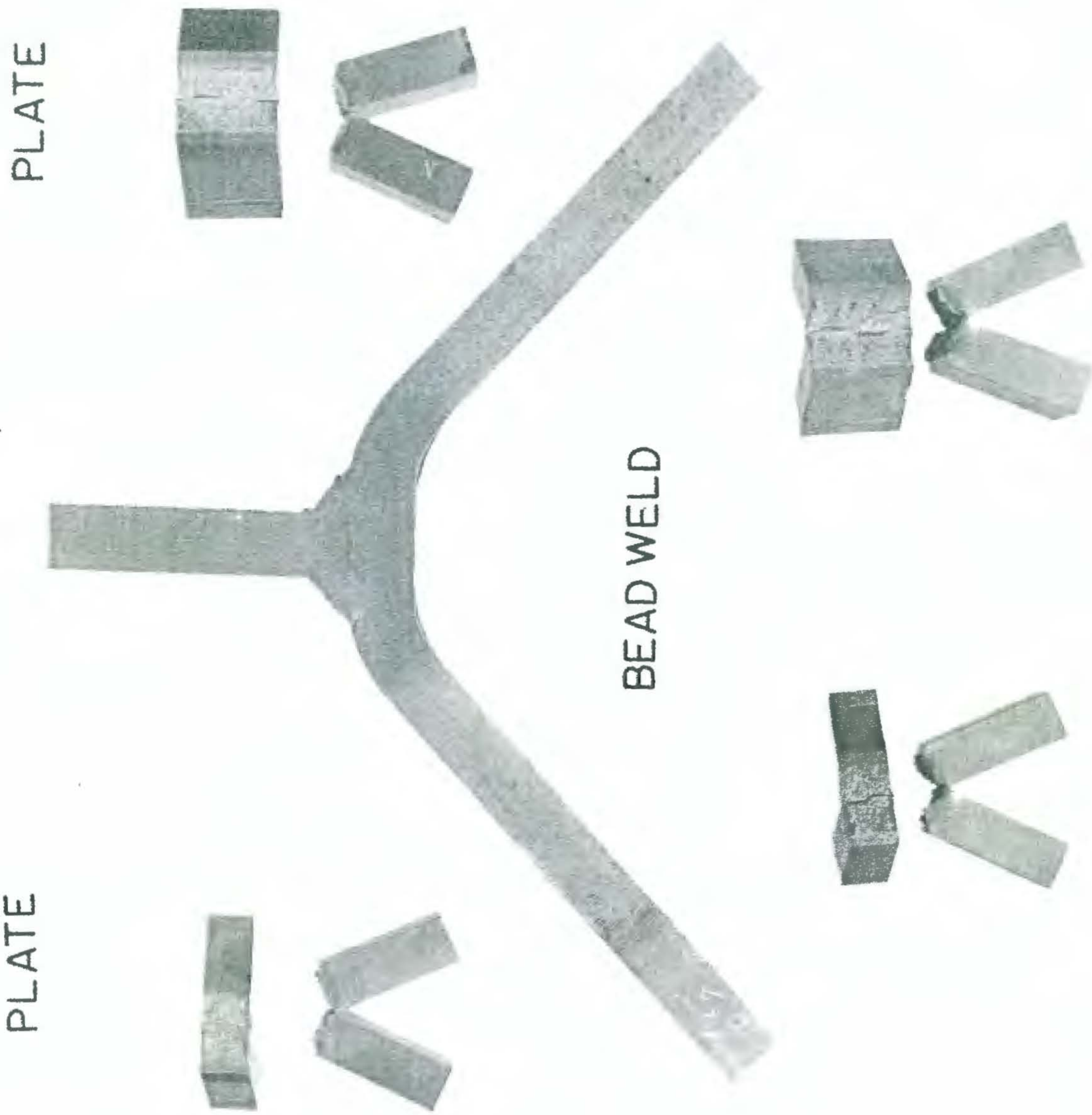

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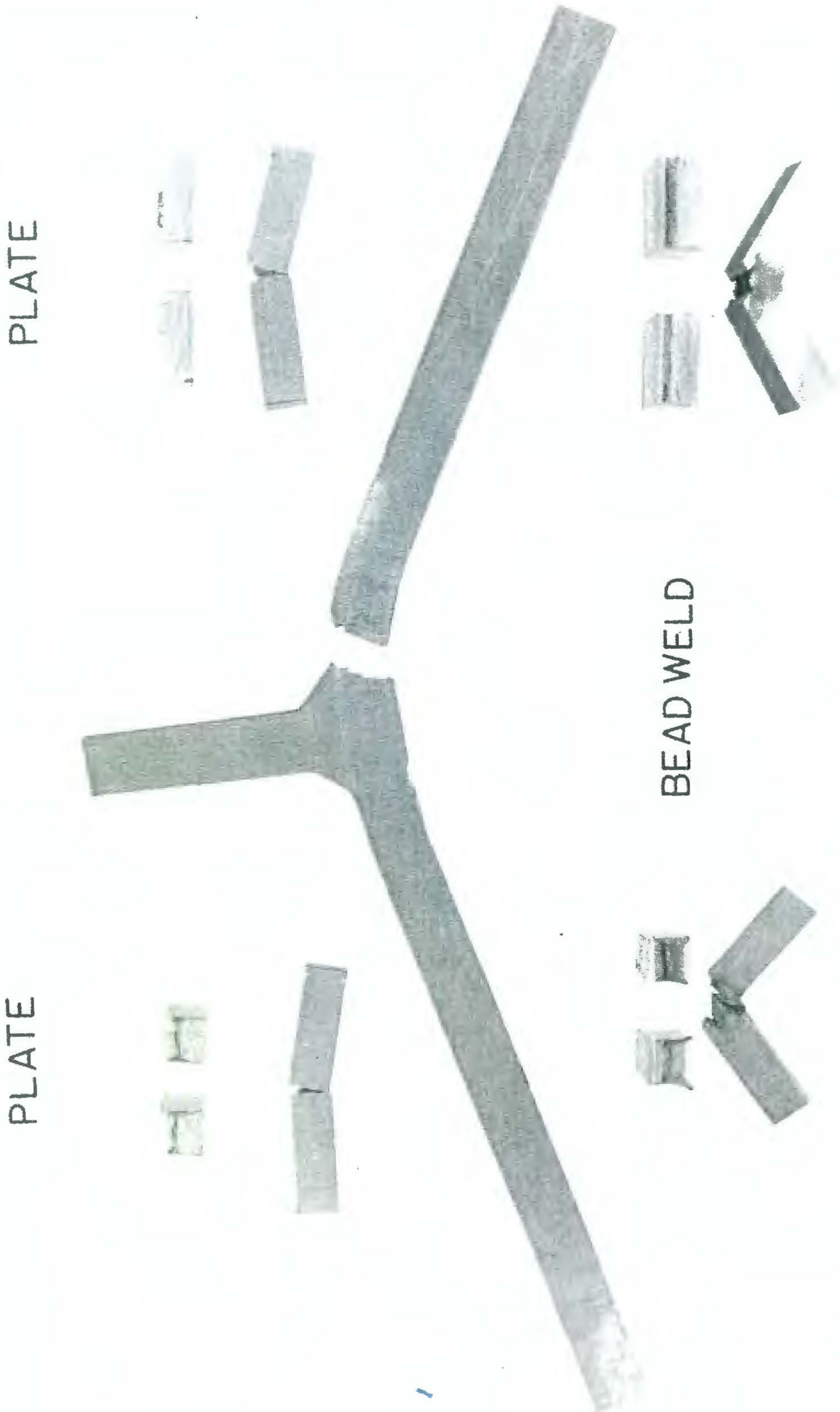

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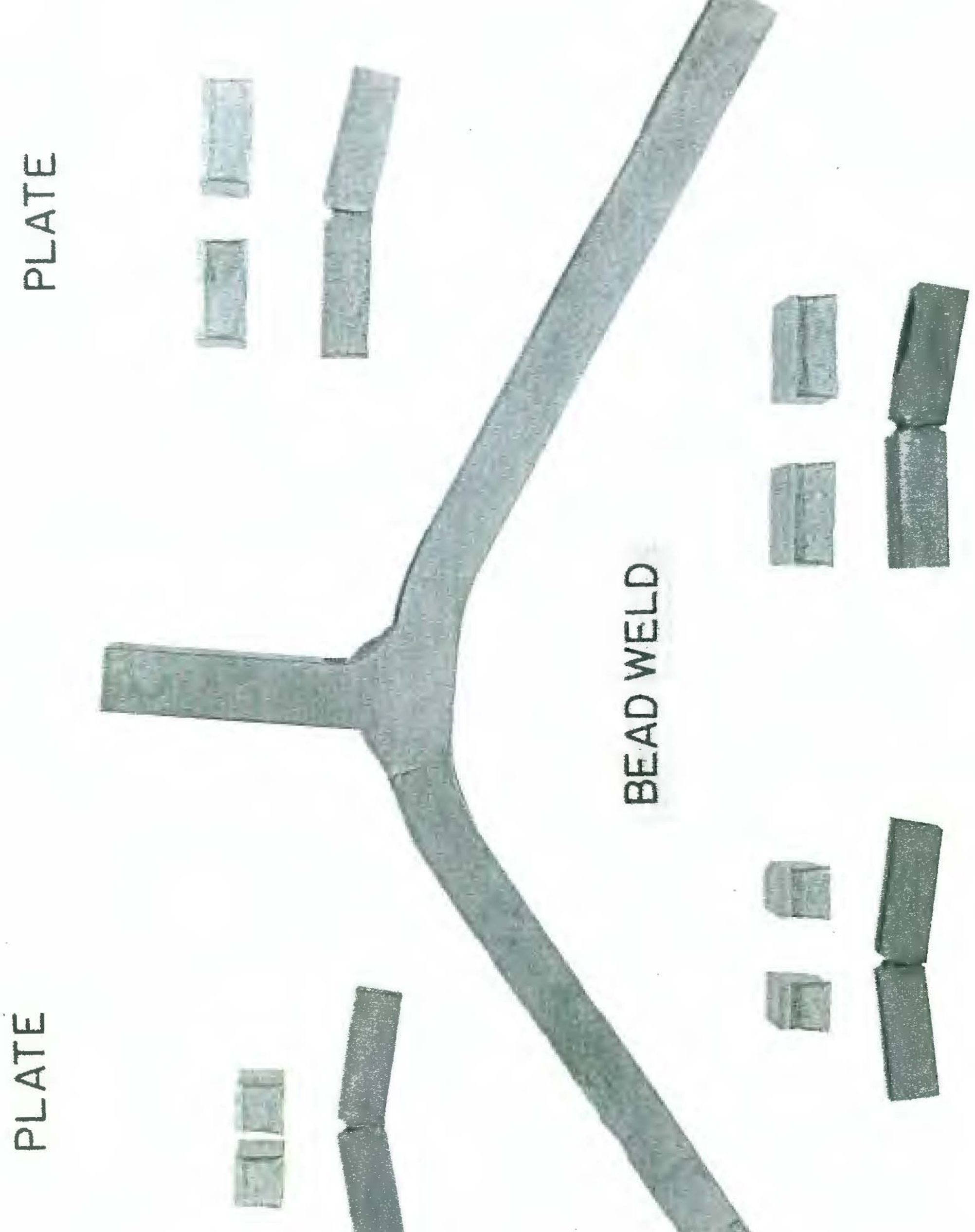

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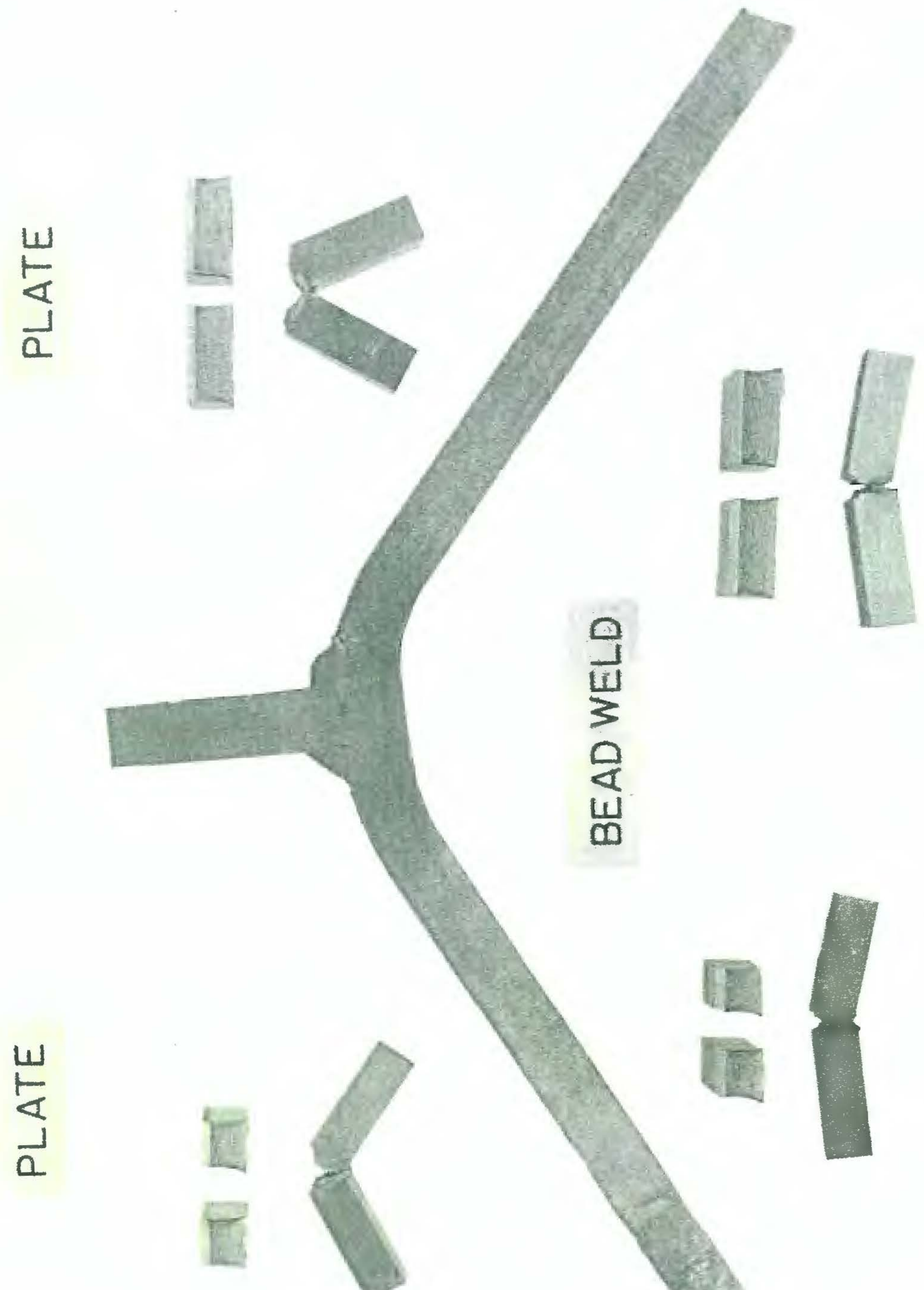

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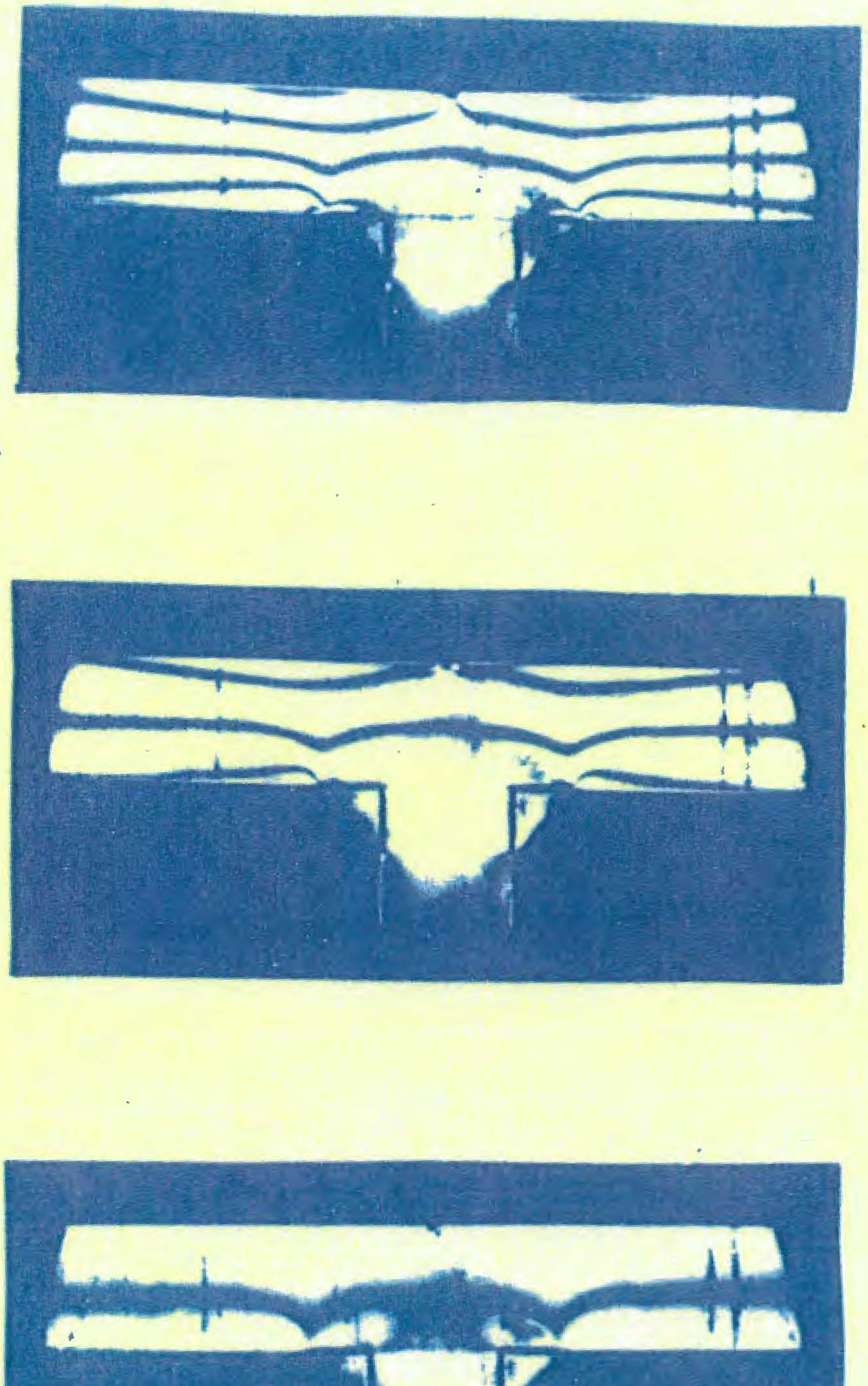

Photo-Elastic Sudy of Tee-Bend

Plate 18