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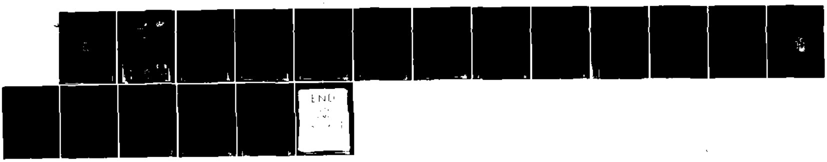

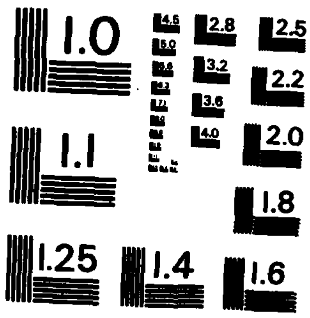

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MEASUREMENT OF VELOCITY AND DISPLACEMENT OF A TRANSVARESTRAINT TESTING MACHINE

N.J. Baldwin and B.F. Dixon

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N.J. Baldwin and B.F. Dixon

ABSTRACT

A transvarestraint testing machine has been instrumented to determine the accuracy of the existing displacement measuring system and to determine the velocity characteristics under test conditions.

Measurements of displacement and velocity were achieved and recommendations for machine and instrumentation improvements have been made.

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Measurements of displacement and velocity were achieved and recommendations for machine and instrumentation improvements have been made.

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MEASUREMENT OF VELOCITY AND DISPLACEMENT OF A TRANSVARESTRAINT TESTING MACHINE

1. INTRODUCTION

The causes of solidification cracking in ferritic steels have been discussed in detail [1]. Three factors which influence crack susceptibility are composition, strain and strain rate [2,3].

The transvarestraint test is one of a number of procedures used to study weld metal solidification cracking [4-6]. This test applies a bending moment to a plate during welding (See Fig. 1). The crack sensitivity of the material is determined by the angle of bending*1 necessary to cause cracking. Early investigators used large forces to ensure that the bending moment was applied rapidly and consequently assumed that variations in velocity were of no consequence. Garland and Bailey [7] however, observed that variation in velocity can occur and, by modifying their apparatus to reduce this variation, improved the reproducibility of their test conditions.

Arata and co-workers [8] modified a small transvarestraint machine so that they could vary its velocity. Subsequent test results on AISI type 310 stainless steel indicated that reducing the deflection rate caused cracks to become progressively longer and the number of cracks to be reduced. They also identified a critical velocity below which no cracks formed regardless of total displacement.

The aim of the instrumentation procedures described in the present paper was to measure the rate of bending due to the ram and, subsequently, to determine the effect of bending rate on the extent of cracking in welds laid on 19 mm thick plates of carbon manganese steel.

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*1: measured as the distance of loading ram travel (displacement).

2. THE MACHINE

The transvarestraint apparatus used in the instrumentation exercise was constructed according to specifications supplied by The Welding Institute, Cambridge, UK [5]. The machine was designed to rapidly apply a predetermined strain across a solidifying weld (see Fig. 1).

2.1 Description of Operation

Air is stored in a 56 litre vessel at approximately 700 KPa pressure. A low pressure system (60 KPa) holds the test plate in contact with a gable-shaped former, with a force of 390 kg. When the welding electrode reaches a position 10 mm from the finishing edge of the test plate a microswitch activates a solenoid valve which dumps air from the storage tank into a pneumatic ram which rapidly bends the test plate over the former via a loading yoke. The maximum force applied by this ram has been statically measured at 4700 kg.

The amount of bending applied to the plate is controlled by presetting the gap between adjustable ram-stops and the yoke. The actual displacement of the loading yoke is monitored by two dial gauges positioned symmetrically on each side of the test plate.

3. INSTRUMENTATION OF THE MACHINE

The electronic instrumentation (see fig. 2) added to this apparatus consisted of two DC.DC displacement transducers (LVDT) mounted coaxially over the dial gauges, and one clip gauge mounted on knife edges between the ram and cylinder. The LVDT's were powered by variable direct current power supplies and their outputs monitored by a digital voltmeter. The LVDT's were calibrated to provide a measure of ram travel and readings were taken before and after each test. The clip gauge was powered by a variable direct current power supply and its output was fed into a transient recorder which stored a selected portion of the output and displayed this on a cathode ray oscilloscope. The transient recorder was triggered by the same microswitch which initiated the ram movement so that the cathode ray oscilloscope displayed clip gauge output against time for the interval during which the ram was in motion. A series of traces recorded by this technique is shown in Fig. 3.

3.1 Calibration

Each LVDT was calibrated with a drum micrometer and its output adjusted to give an output of 1 volt per millimetre of displacement.

The clip gauge was calibrated with a micrometer head and its output adjusted to give an output of 5 mV per millimetre of displacement.

The transient recorder and cathode ray oscilloscope were adjusted to produce 2 divisions of oscilloscope displacement per millimetre displacement of the clip gauge (i.e. Full scale displacement of 8 divs = 4 mm clip gauge displacement).

4. EXPERIMENTAL

In order to determine the effect of using different welding processes on the rate of displacement a series of three transvarestraint tests involving submerged arc (SA), metal inert gas (MIG) and simulated manual metal arc (SMMA) welding were conducted. The three series of tests were intended to have the same heat input, weld metal composition and surface profile. The full results of these including weld metal compositions and welding process variables are contained in another report [9].

In addition to the above, a subseries of four tests using SA welding was conducted with reduced pressures in the storage tank.

5. RESULTS

Load displacement curves recorded from the cathode ray oscilloscope were analysed to determine "velocity" (v) and "maximum velocity" (v_{max}) as illustrated in fig. 4. These velocities were averaged for each of the test series and the results are presented in Table 1.

The velocities were then regrouped into ranges of deflection and the average velocity for each group is recorded in Table 2.

Values of standard deviation (s) were calculated for each grouping in Tables 1 and 2.

The most significant result is that the average velocity of the MRL transvarestraint machine is a nominal 1.0 mm/sec. The standard deviation values indicate significant variations in test velocities.

6. DISCUSSION

Although a three point loading rig applies a bending moment to the test specimens, all movement has been measured in terms of ram deflection. The actual angle (θ) through which the plate is bent is calculated by

$$\theta = 2 \arctan \frac{2d}{l}$$

where d = "displacement"
l = distance between loading pins (see Fig. 1)

As a result of early experiments, certain improvements were made to the machine. Firstly, the original dial gauges were replaced by more accurate metric dial gauges mounted in a follow down configuration for gauge protection. Secondly, the screw threaded ram stops were calibrated to improve the convenience and reliability of presetting the ram gap.

The electronic instrumentation of the transvarestraint testing machine provided an indication of the velocity and displacement of the loading ram during a number of tests.

The results of these experiments have provided useful information about the operation of the transvarestraint test. It had been anticipated, for example, that different welding procedures may result in different ram velocities even though the same rate of heat input was used. As can be seen in Table 1, the average velocity is 1.0 mm per second for SA and MIG, and 0.9 mm per sec for SMMA. In addition, the value of average maximum velocity is 1.2 mm/s for SA and MIG and 1.1 mm/s for SMMA. Allowing for the considerable scatter of results indicated by standard deviation values ranging from 0.1 to 0.6, the variation in ram velocities are insignificant, and therefore considered to be unaffected by the welding process.

In theory, the ram force is dependent on the pressure in the storage tank. In one series of tests (DW 22-25) the maximum pressure in the tank was regulated down to 40% of the operating pressure in the hope of introducing a controlled, lower ram velocity. Progressively reduced ram velocities were achieved, although the lowest ram velocity, i.e. 0.7 mm/s, had also occurred with maximum pressure in the storage tank. The four results were therefore averaged and the results recorded in Table 1. Comparing the "full pressure" and "low pressure" results in Table 1, it can be seen that the decrease in velocity was almost negligible.

The shape of the ram displacement versus time curve showed, in most instances, that during each stroke the ram accelerated to a relatively constant velocity. The transition from acceleration to constant velocity occurred at various times and displacements, suggesting that the restraining force in each test plate varied.

Statistical analyses summarised in Table 2 show the relation between ram velocity and final displacement. These figures show an increasing ram velocity (both mean and maximum) with increasing final displacement. This indicates that the ram may be accelerating for up to 2 mm displacement.

The considerable variation in velocity identified by these tests indicates that certain modifications to the test apparatus are desirable. These modifications are discussed below.

Firstly, the acceleration of the ram and yoke assembly is proportional to the force generated by the ram minus the restraining force in the test plate. The low pressure tests indicate a restriction between the storage cylinder and the ram. Because air has to be admitted to the pneumatic ram there is a time delay before the pressure in the ram builds up from the hold down pressure to the maximum pressure in the storage cylinder. Maximum acceleration of the ram would be achieved by applying maximum pressure to the ram before test initiation. This requires a restraining force to prevent the test plate being bent before welding and a controlled means of removing the restraining force to control the velocity of the ram.

Secondly, it is noted that many plots of displacement against time show discontinuities; these are probably caused by rocking of the test plate while it is being welded. The problem may be reduced by guiding the loading yoke throughout its travel. Rocking of this nature would also cause inaccurate measurements of velocity to be recorded at the clip gauge. It is therefore suggested that the clip gauge be relocated to a position on the side of the loading yoke and vertically beneath the gable shaped former.

These changes would permit the use of a single displacement transducer and, therefore, reduce the amount of work involved in processing results.

Finally, the agreement between static measurements made by the LVDT's, dial gauges and clip gauge was good. However the displacements as measured from the dynamic clip gauge output differed from the static clip gauge measurements, sometimes being higher and sometimes lower. This probably occured because the thermal shrinkage forces associated with welding were not always balanced by the "hold down" forces applied by the loading yoke. This allowed the ram to move slightly from its preset position. This affected only the clip gauge trace.

7. CONCLUSIONS

Investigations of the MRL transvarestraint machine revealed the following:

1. Averaging of the displacements as measured by the two dial gauges provided a reliable measure of ram displacement.

2. Discrepancies between the preset ram displacement and measured ram displacement were reduced to within 0.1 mm by calibrating the restraining stops.

3. The mean of the average ram velocities for 31 test runs was 1.0 mm per second. The lowest recorded average velocity was 0.5 mm/sec and the highest was 1.7 mm/sec. The mean of the maximum ram velocities was 1.2 mm per second.

4. Ram velocities increased with increasing ram deflection.

5. This transvarestraint machine requires modification to provide reliable testing at different ram velocities. These modifications should include improved dynamic velocity measuring instrumentation, introduction of a velocity control system and elimination of side movement in the ram.

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T A B L E 1

STATISTICAL ANALYSIS OF DEFLECTION RATES FOR THREE DIFFERENT WELDING PROCESSES

TEST SERIES	NO. OF TESTS	AVERAGE DEFLN. RATE		AV MAX. DEFLN. RATE	
		v mm/s	s mm/s	v_{max} mm/s	s mm/s
SA					
Full Pressure (DW01-20)	13	1.0	0.3	1.2	0.6
Low Pressure (DW22-25)	4	0.9	0.3	1.1	0.5
MIG (DW26-37)	6	1.0	0.1	1.2	0.3
SMMA (DW38-49)	8	0.9	0.1	1.1	0.2

T A B L E 2

STATISTICAL ANALYSIS OF DEFLECTION RATES FOR DIFFERING GROUPS OF DEFLECTION VALUES

TEST SERIES	NO. OF TESTS	AVERAGE DEFLN. RATE		AV MAX. DEFLN. RATE	
		v mm/s	s mm/s	v_{max} mm/s	s mm/s
0-0.5 mm Defln.	10	0.9	0.2	0.9	0.2
0.5-1.0 mm Defln.	8	0.9	0.2	1.2	0.3
1.0-2.0 mm Defln.	8	1.1	0.2	1.4	0.3
2.0-3.0 mm Defln.	6	1.5	0.3	3.2	2.3

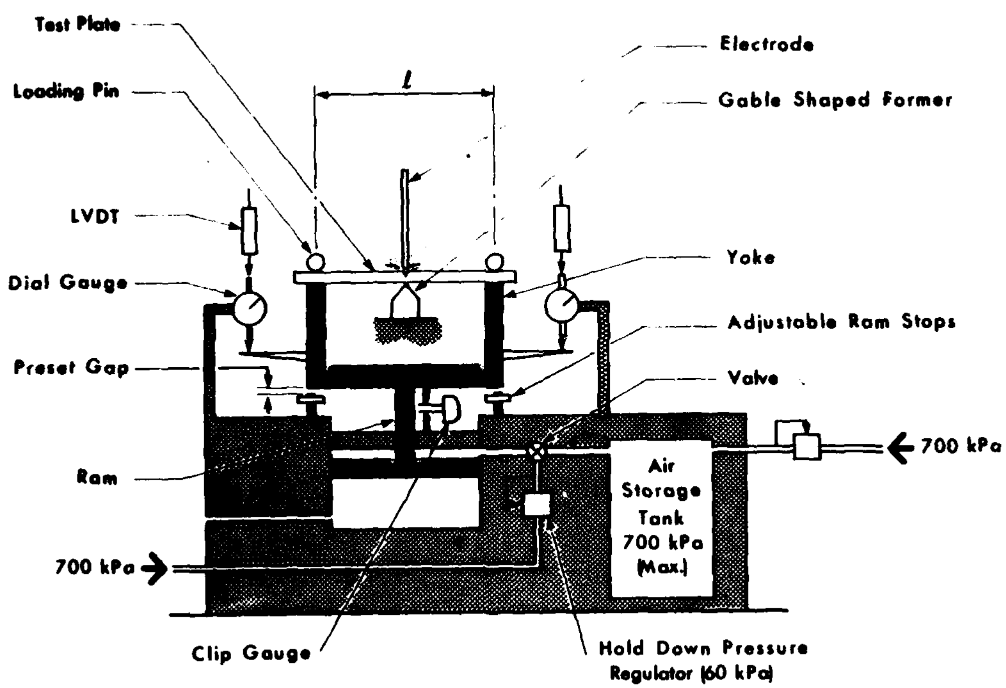


FIG. 1 Schematic diagram of MRL transvarestraint machine.

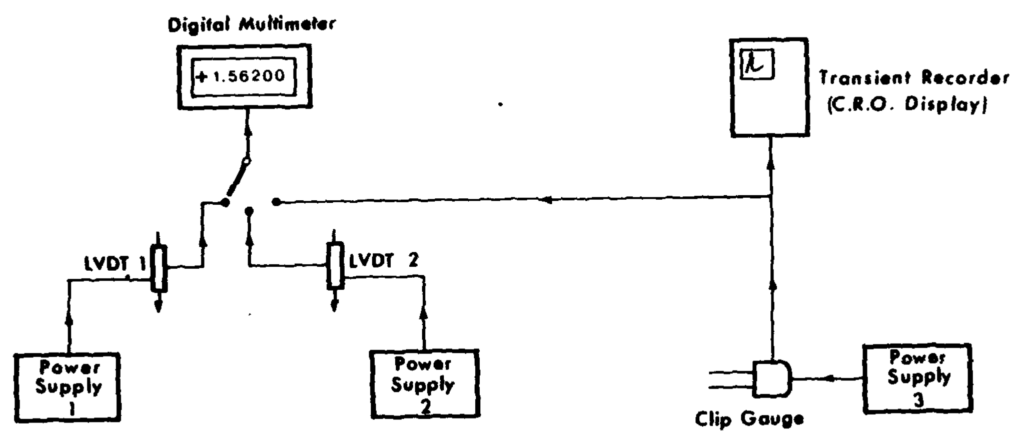


FIG. 2 Schematic Diagram of Instrumentation

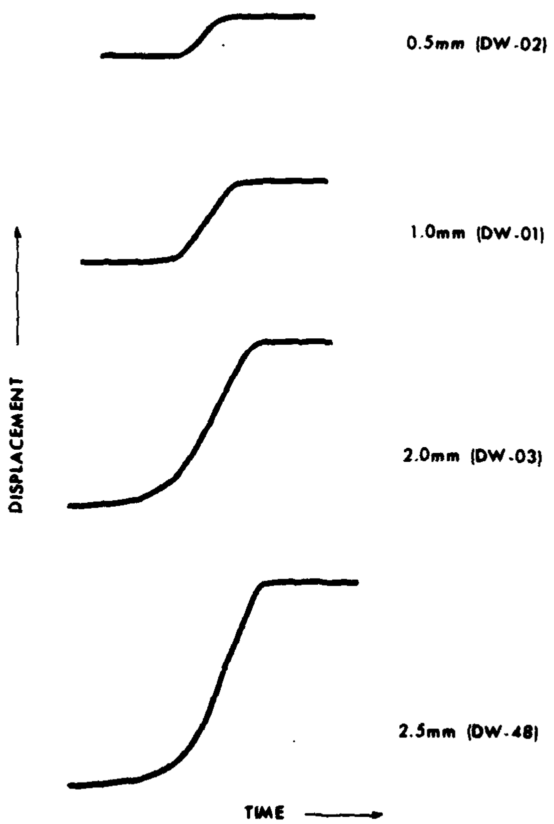
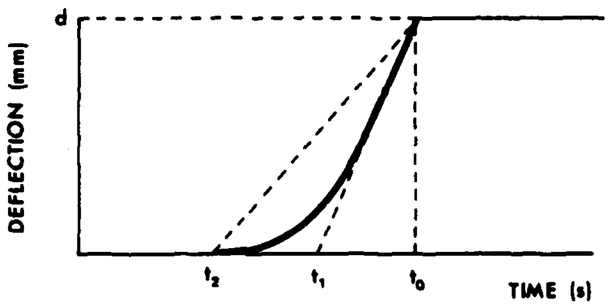


FIG. 3 Displacement versus time curves depicting ram velocities.



$$\text{average velocity} = \frac{d}{t_o - t_2}$$

$$\text{maximum velocity} = \frac{d}{t_o - t_1}$$

FIG. 4 Methods of calculation of average and maximum ram velocities.

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