Report on Welding Metallurgy of Girth Weld Defects in Mechanised GMA Field-welded Pipe Lines

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INTRODUCTION

Mechanised Arc Welding

The terms semi-automatic arc welding and fully automatic arc welding are wel-known, yet they need to be cleanly demarcated. In semi-automatic welding the wire feeder maintains the arc and feeds the wire, the operator's job is to manipulate the arc along the joint. In fully automatic welding all the welding parameters are oresent and the entire operation from start to finish is accomplished by the equipment. The operator's role is nill.

Fully automatic welding demands compensate sophisticated controls and perfect fit-up and alignment of the joint. Semi automatic welding on the other hand, uses standard welding equipment and provides the flexibility of negotiating variable and irregular joints not possible with fully automatic welding.

Mechanised welding is an intermediate step between semi-automatic and full automatic versions. In mechanised welding the wire feeder maintains the one and feeds the filler wire, and travel device provides relative motion between the arc and the joint. The welding operation is very much involved, he constantly monitors and adjusts the equipments to provide a consistent high quality weld. The welder fatigue factor and arc stoppages factor are eliminated. Instead of doing the actual welding work, the welding operator plays a monitoring role by controlling high currents and high duty cycles. In this way, the operator factor and deposition rate are greatly increased, thereby leading to increased productivity, less distortion & reduced welding costs.

The processes which can be easily mechanised are submerged arc welding MIG/CO2 welding and flux-cored arc welding. Submerged-arc welding needs flux to be replaced on the joint in advance of the arc, which is not always possible. Also the arc being invisible, the monitoring is not easy. MIG/CO2 and flux-cored arc do not suffer from there constraints. TIG welding with automatic wire feed is also successfully used in some applications.

Girth Weld Defects In Mchanized GMA Field-welded Pipelines.

Analysis of nearly 60,000 welded joints in pipelines shows defect incidence connected to season, pass, quadrant and project size. :-The mechanized welding system used on all jobs was first introduced in 1968, and to date over 19,000 K.M. of pipelines ranging in size from 406 to 1524 mm in diameter have been installed in all types of environment

Figure 1 shows a typical "spread" in use in the field.

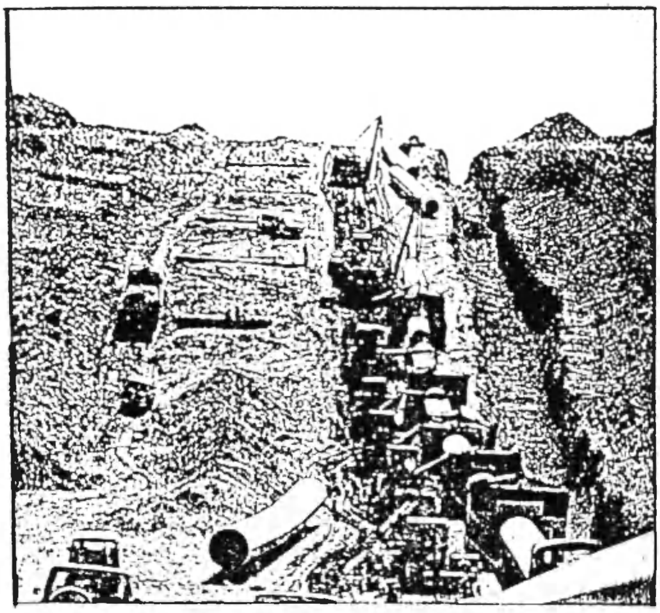

Fig. 1 : Typical field setting for automatic Pipe line welding operation.

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The system is not an "automatic" system in the strictest sense. The only fully ayromatic component is the internal line-up clamp-welding machine and, even then, this device requires skilled tradesmen to control its travel and initial alignment at each weld, as well as to maintain it. The system is more accurately characterized as a mechanical system. Details regarding system operation are provided.

The use of High-strength, low-carbon-content large-diameter heavy-wall line pipe by Canadian natural gas transmission companies in recent years has promoted the use of mechanized welding. Such line pipe has typically been specified as having a minimum yield strength of 448 MPa or greater and a carbon content of less than 0.10%. Pipe diameters in the range of 914 to 1218 mm and wall thickness in the range 8.81 to 19.34 mm have been common. The trend in material selection is clearly toward higher yield strengths and heavier wall thicknesses and, in general, more difficulties for the pipeline contractor in terms of pipe weldability.

Contractors have found that conventional shielded metal arc or manual welding of these higher grades of steel under field conditions often result in an unacceptable combination of low production and high repair rates. To alleviate this situation, owning companies encouraged contractors to introduce mechanized welding to their operations. Early results suggested that a better compromise between weld production and repair rates could be achieved. It is noted, however, that site-specific conditions may vary considerably from project to project and that variation may have a significant impact on repair rates and the occurrence of defects in general.

There is a distinction between a "repair" and "Defect" in this report. A defect is a discontinuity which exceeds by some measure, usually linear a limiting value as expressed in the workmanship standards embodied in the regularitory codes to which pipelines are designed and constructed. The most common defects found in pipe welds are melt-through cracks, incomplete fusion and porosity. A defect may also be deemed to be threatening to the structural integrity of the pipe line on the basis of an engineering critical assessment(E.C.A.)

A repair on the other hand refers to a weld containing one or more defects note complying with the fabrication code and which must be repaired. From the perspective of the contractors cost to repairs a defective weld law incremental cost is incurred when repairing a weld with multiple defects as opposed to a weld containing a single defect. By far the greatest cost component of the repair is related to the remobilization and initial set-up activities associated with the repair operation. Thus the motivation is to reduce the repair rate and note necessarily the frequency of occurrence of single or multiple defects or that of specific types of defects.

This study examined are number of projects characteristics or conditions which affect overall quality. One objective was to developed one or more models incorporating a variety of job characteristics to predicts to repair rate and frequencies of occurrences of specific defect types. Armed with such information a contractor may be able to reduce overall construction costs.

Data Analysis

The development of models involving procedural and environmental variables was made on the basis an analysis of repair rate and defect occurence histories of nine construction projects involving more than 59000 welds. Each project involved varying climatic conditions and terrain types. The work was performed for two unrelated pipeline- owing companies by four different contractors, all four contractors had previous experience with the mechanized welding equipment and procedures employed for cross-country pipeline welding application. Table1 is a summary of the primary characteristics of the projects.

TABLE 1 - Summary of Project Description

Project	owner	Contractor	pipe	Length	Season
1	1	A	914 mm X Gr 483	11 Km	Winter
2	2	A	1218 mm X Gr 448	291 Km	Summer
3	2	A	914 mm X Gr 448	232 Km	Summer
4	1	A	1067 mm X Gr 483	8 Km	Summer
5	1	B	914 mm X Gr 483	93 Km	Winter
6	1	C	1067 mm X GR 483	161 Km	Winter
7	2	D	914 mm X Gr 448	190 Km	Summer
8	2	D	1218 mm X Gr 448	186 Km	Summer
9	2	C	1067 mm X Gr 483	203 Km	Winter

The nondestructive examination and subsequent documentation of defects for each of the welds made on the nine jobs was conducted in accordance with normal pipeline construction practices.

The Total mileage installed was some 1475 Kms of large diameter transmission line involving the completion of 59,520 girth welds on 80-ft sections using the mechanized welding system. Of those welds, 12,444 were defective, thus requiring repair. The defective welds contained a total of 16,653 individual defects. Each girth weld was completely radiographed as was each repaired weld. Seventeen characteristics, each suspected of being related to weld quality, were use to describe each defect recorded in the database, were use to describe each defect recorded in the database. They included : owning company, contractor, pipe size and grade date on which weld was radiographed, type, location and length. For purposes of analysis, a useful segregation of circumferential defect locations by quadrant was employed : top, bottom, workside and ditchside. The top quadrant, looking from the open end of the pipe is from -45 deg to 45 deg and the bottom quadrant is from 135 to 225 deg. The ditchside quadrant is from 45 to 135 deg and the workside quadrant is from 225 to 315 deg.

Several categories of defect type were combined for the statistical analysis. For example, undercut is grouped with incomplete fusion. Therefore all defects were combined for analysis on the basis of a four weld pass configuration consisting of root, hot, hot fill and cap passes.

Two-way and multi-way frequency tables were prepared as a first step in describing and organizing the data. Preparation of two- way frequency tables was also useful for the calculation of gross statistics for the sample. Chi-square tests of independence for all pairs of variables were conducted. The Chi-square test statistically determines if a particular observed data a set differs significantly from an expected pattern. This is a primary tool in the analysis of relationships between variables cross- tabulated into multiway frequency tables.

A simplified correspondence analysis suitable for visual interpretation of two-way table was conducted to convert frequency table data into graphical displays in which rows and columns are depicted as points. This provides a method for comparing row or column proportions in the table.

Results

Repair rate Analysis

Table 2 lists the repair rate summary by project. Projects were classified as "large" when more than 10,000 welds were involved, and "small" if less than 5000 welds were done.

Table 2 Repair rate Summary by Project

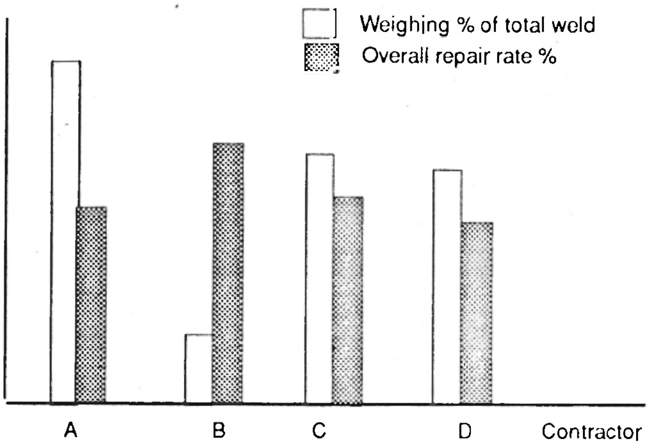
Project	Total welds	Welds Reoaired	Repair Rate, %
1	4,308	1,592	37
2	12,439	2,123	17
3	8,154	906	11
4	298	91	31
5	4,034	1,278	32
6	6,889	1,201	17
7	5,873	1,443	25
8	7,777	1,166	15
9	9,748	2,644	27
Totals	59,520	12,444	21% average

The result of statistical calculations suggests that variations in certain categories of characteristics have more influence on repair rates than do variations in others. Repair rates during the early productions stages of a project tend to be high relative to the overall repair-rate statistics for a project as determined as its conclusion.

Repair rates for the various project sizes, Table-2, agree with the hypothesis that larger projects tend to have lower repair rates as a results of the diluting impact of quantity on relatively poor quality performance during the start-up period. Note, however that five project fell into the mid size category and only one in the largest category. In addition, the largest project (by contractor A) represented 21% of all welds completed and was done during the summer season, when repair rates are lower. Overall repair rates by owning company, contractor, season and other variables are given in Table - 3.

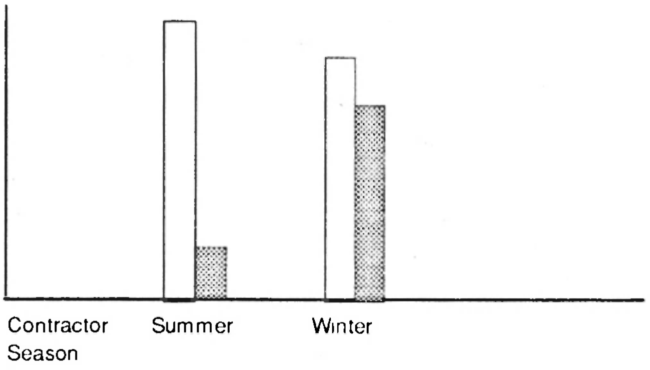
Table-3 Overall Repair Rate Measures :

	Weighting % of total Welds	Overall repair rate %
Owning Company		
1	26	27
2	74	19
Contractor		
A	42	19
B	7	32
C	28	23
D	23	19



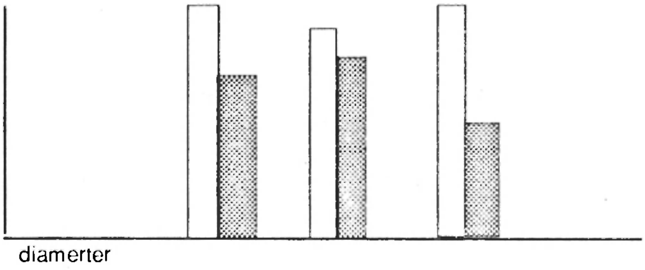
BAR CHART FOR Table-3
Contractor + % of total welds 4% of overall repari rate

Contractor Season		
Summer	58	17
winter	42	27



BAR CHART FOR Season Cs % of total welds & repair rate

Pipe diameter		
914 mm	38	23
1067 mm	28	23
1218 mm	34	16



Bar chart for Table 3
Pipe diameter Vs. % of weighing total welds & over repair rate

Pipe grade		
Grade 448	58	21
Grade 483	42	37

Project size, Welds/projec			
<5000	15	34	
5000 to 10000	64	19	
>10000	21	17	
Fill pass condition, # of passes			
1	21	49	
2	(—)		21
3	(79)		10

Overall repair rate by ownings company, contractor, season and the variable are given in table-3, Contractor A had an overall repair rate of 19%, but this contractor completed about 42% of all Welds and constructed 45% of all projects investigated; it had to contain with four start up period.It also completed the smallest project studied one involving only 298 welds, where the repair rate was 31%.

Owning company one welds were subject to 27% repair rate while those of company 2 had a repair rate of 19%. However, most of owning company ones projects were done in the winter while, most of the other projects were done during the summer season. Of the total five projects were completed during the summer season while four were done during the winter. The average project size was about the same for each season's work but the repair rate were 17% for the summer & 27% for the winter work. On the basis of this comparison alone, one is inclined to conclude that winter work takes its toll on weld quality much more so than that done in the summer.

The chi-square test for independence was applied to pairwise comoponents of the repair rate data. This test provides an index used to assess departure from pairwise independence. The chi- square values range from 17.5 for owner verses season to 42.6 for the season Vs. defect concentration combinations of repair-rate occurrences. It is easy to conclude that in the case of the conbinations of project characteristics considered the probability of obtaining such large chi-square values is vary small. The degree of association between season & defect concentration is more pronounced than that between season & owner.

Defect Frequency Analysis.

Defect description (type, length and concentration) and defect location (pass notation and circumferential location) characteristics were analyzed to see if preventive action could be prescribed. Table 4 & 5 summarized some of the defect frequency measure investigated.

Loglinear analysis of the total sample indicates clearly that relationships between the variables defect type, concentration, start of defect quadrant and pass were all significant, i.e., there was a probability greater than 99% that the variables were not independent. The size of the total sample was 16.653 defects. Analysis indicates that all second order models and some third and forth order models involving certain combinations of the four variables were significant. A correspondence analysis of the second order models helps to identify how the categories of each variable are interrelated in a synergistic fashion.

Key relationship defected as a result of this analysis of the total sample are included in table 6

Table 4 Over all Defect Concentration Summary

Defects/Weld	Proportion of All Welds Made, %
0	79.1
1	15.7
2	3.8
3	1.0
4	0.3
5	0,1
6	nil
7	nil
8	nil

Table 5 - Overall Defect Frequency Measures

Defect Classifications :	Proportion of All defects Recorded, %
Incomplete penetration	4.1
Burn through	2.6
Incomplete fusion	66.9
Porosity	22.0
Other	1.3
Cut outs	3.3
Wall Thickness :	
0.347 in (8.80 mm)	17.8
0.385 in (9.79 mm)	23.7
0.389 in (9.88 mm)	8.5
0.400 in (10.16 mm)	14.3
0.457 In (11.61 mm)	23.4
0.462 in.(11.73 mm)	0.3
0.504 in. (12.80 mm)	1.4
0.551 in. (14.00 mm)	8.0
0.554 in. (14.07 mm)	0.6
0.559 in (14.10mm)	0,8
0.609 in. (15.47 mm)	1.2
Fill Pass Condition -# of fill passes :	
1	50.0
2	41.0
3	9.0
Pass Location :	
not recorded	1.5
root	23.9
hot	10.7
1st fill	35.9
2nd fill	13.3
3rd fill	10.5
cap	4.2

Table 6 : Loglinear Analysis for Relationship between variables

Variable pairings relationships

TYPE/CONCENTRATION

- The occurrence of cracks (cut outs) demonstrates a strong positive association with high multiple defect concentrations.
- Other combinations of categories demonstrate little Association.

PASS/CONCENTRATION

- Little association is apparent between the categories of pass in which a defect is found and the concentration categories of defect in a defective weld.

START-OF-DEFECT/QUADRANT

- Single and other low multiple defect concentrations show a positive association with the workside quadrant (225-315 deg).
- Little association is evident between other quadrants and defect concentrations.

TYPE/PASS

- The relationships between categories of these two variables are largely set by definition. For example, insufficient cross penetration is by definition is defect occuring only in the hot pass and underfill can only occur in the cap pass. As a result, the categories of type and pass are not well summarized by the dimensions of the other variable for any clear reason other than definition.

TYPE-OF-DEFECT/QUADRANT

- The occurence of melt through, underfill, crack (cut out), incomplete fusion (interpass side wall) and undercut demonstrate a large positive association with the workside quadrant.
- A strong negative association is evident between the defect insufficient cross-penetration and the workside quadrant.
- Little association exist between the remainder of the defect types and segments of the pipe's circumference.

PASS/DEFECT QUADRANT

- The variables are well defined with respect to one another but little association is distinguishable at the Category level.

In 1975 to 1985 repair rates in the range of 15 to 35% could be expected due to a variety of factors, including the novelty of mechanised pipe welding. Presently, expected repair rates are 5 to 10%. One can estimate that the rate will tend towards the higher and of this range, if the project can be defined in terms of one or more of the following charateristic :

- Construction to be completed during the winter season.
- Pipe dia. less than 1218 mm.
- Pipe material grade greater than Grade 448 Mpa

- Welding procedure specifies single fill pass condition
- Project size in terms of no. of welds is less than 5000.

Defect Frequency Expectation

When the repair rate of mechanised welding of pipe lines is in the range of 15 to 35% the following conclusions can be drawn as a result of loglinear analysis.

- Most defective welds contained a single defect but the average was about 1.3 defects.
- Most defective welds having a high concentration of defects result in a cutout.
- Defects in general were most frequently found in the fill (60%) and root (24%) passes.
- A higher frequency of defects occured in the welding procedure specified a single rather than a two-fill condition.
- The most frequently occuring defect types were the categories of incomplete fusion of sidewall is 31% & of interpass and undercut is 24% and porosity is 21%.
- The majority of this defects were found in the fill passes, the incomplete sidewall fusion being the predominant fusion defect type.

Defect Causes and Cures

The analysis of the data has indicated a distinct tendency for defects to occur most frequently in the root & fill passes and for their starting location to be in a workside quardant. These results should prompt the contractor and inspection staff to be particularly attentive to the welding procedure in this areas.

The prominence of fill pass defects and their location on the work side suggest that attention should be given to welding operator skill level and training needs with respect to the fill pass bugs as well as manufacturer attention to the basic design of the external welding units as they are used on the workside of the pipe. The bug passes into the lower portion of the workside quadrant, and the welder has to follow it into the bottom quadrant, all the while visually monitoring the weldpull and managing its behavior through manipulation of the two control knobs. A loss dexterity, resulting from constraints in the use of right and left hands to control the equipment can be noted when matching the operation.

For improved weld quality the most appropriate materials should be selected including welding consumables all materials should be properly stored ans protected. Welding procedures should be carefully tested, documented and approved. Welding equipment should be properly designed and maintained and all welders and their helpers should be properly, skilled, trained, supervised and have their work promptly and adequately inspected.

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