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Inspection of Fusion Joints in Plastic Pipe

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Measurement Units -- SI Metric System of Units are the primary units of measure for this report followed by their U.S. Customary Equivalents in parentheses ( ).

Note: SI is an abbreviation for "Le Systeme International d'Unites."

ABSTRACT

The standard method of joining plastic pipe in the field is the butt fusion process. As in any pipeline application, joint quality greatly affects overall operational safety of the system. Currently no simple, reliable, cost effective method of assessing the quality of fusion joints in the field exists. Visual examination and pressure testing are current non-destructive approaches, which do not provide any assurance about the long-term pipeline performance.

This project will develop, demonstrate, and validate an in-situ non-destructive inspection method for butt fusion joints in gas distribution plastic pipelines. The inspection system will include a laser based image-recognition system that will automatically generate and interpret digital images of pipe joints and assign them a pass/fail rating, which eliminates operator bias in evaluating joint quality.

A Weld Zone Inspection Method (WZIM) is being developed in which local heat is applied to the joint region to relax the residual stresses formed by the original joining operation and reveal the surface condition of the joint. In cases where the joint is not formed under optimal conditions, and the intermolecular forces between contacting surfaces are not strong enough, the relaxation of macromolecules in the surface layer causes the material to pull back, revealing a fusion line. If the joint is sound, the bond line image does not develop.

To establish initial feasibility of the approach, welds were performed under standard and non-standard conditions. These welds were subjected to the WZIM and tensile testing. There appears to be a direct correlation between the WZIM and tensile testing results. Although WZIM appears to be more sensitive than tensile testing can verify, the approach appears valid.

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1.0 - INTRODUCTION

Improved plastic pipe weld inspection methods with increased reliability are an attractive alternative to conventional methods, which include visual inspection, pressure testing and destructive testing. As in any pipeline application, the quality of the joints greatly affects the overall operational safety of the system. While major failures of polyethylene pipe butt fusion joints are fortunately infrequent, the consequences of a plastic gas pipeline failure can be severe and result in:

- Damage to the pipeline system and surrounding environment
- Risk of fire or explosion
- Risk to human personnel
- Interrupted service
- Significant monetary losses

The situation is compounded by the fact that there is currently no simple, reliable, cost effective method of assessing the quality of fusion joints in the field. Current practice is to inspect plastic pipe joints by visual examination followed by pressure testing. This approach does not provide any assurance of long-term pipeline performance.

2.0 - EXECUTIVE SUMMARY

Plastic pipe has been used successfully by the natural gas industry for nearly three decades for applications ranging from low-pressure transmission pipelines to residential distribution lines. The standard method of joining plastic pipe in the field is the butt fusion process. As in any pipeline application, joint quality greatly affects overall operational safety of the system. Currently no simple, reliable, cost effective method of assessing the quality of fusion joints in the field exists. Visual examination and pressure testing are current approaches, which do not provide any assurance about the long-term pipeline performance.

This project, which builds off of previous work co-funded by NYSEARCH (formerly NYGAS) and Edison Welding Institute, will develop, demonstrate and validate an in-situ non-destructive inspection method for butt fusion joints in gas distribution plastic pipelines. The inspection system will include a laser based image-recognition system that will automatically generate and interpret digital images of pipe joints and assign them a pass/fail rating, which eliminates operator bias in evaluating joint quality.

A Weld Zone Inspection Method (WZIM) is being developed in which local heat is applied to the joint region to relax the residual stresses formed by the original joining operation and reveal the surface condition of the joint. In cases where the joint is formed under non-optimal conditions, and the intermolecular forces between contacting surfaces are not strong enough, the relaxation of macromolecules in the surface layer causes the material to pull back, revealing a fusion line. If the joint is sound, the bond line image does not develop.

To establish initial feasibility of the approach, welds were performed under standard and non-standard conditions. These welds were subjected to the WZIM and tensile testing. There appears to be a direct correlation between the WZIM and tensile testing results. Although WZIM appears to be more sensitive than tensile testing can verify, the approach appears valid.

Successful implementation of the proposed innovative non-destructive in-situ inspection method will offer the following benefits:

- Improve the reliability and safety of plastic pipe systems for natural gas distribution.
- Minimize the cost and need for expensive destructive quality assurance (QA) tests.
- Increase the confidence in the use of plastics for pipes in safety critical applications or where the cost of failure would be high.

3.0 - EXPERIMENTAL

3.1 Preparation of Fusion Joint Samples

EWI and NYSEARCH identified the most commonly used plastic pipe materials and sizes used by gas distribution companies, NYSEARCH-members. As shown in Table 1, Driscopipe 8100, Driscoplex 6500 and 6800 in the 101, 152 and 203 mm (4, 6 and 8 inch) diameters were selected by the industrial partner to be the most commonly used materials and sizes.

Table 1 Experimental Matrix of Pipe Specimens

Pipe type	Material	Diameter	SDR
Driscoplex 6800	PE3408	101 and 152 mm (4 and 6 inch)	SDR11
Driscopipe 8100	PE3408	203 mm (8 inch)	SDR11 and SDR10
Driscoplex 6500	PE2406	101, 152 and 203 mm (4, 6 and 8 inch)	SDR11.5 and SDR13.5

Butt fusion joints were produced at two NYSEARCH-member company locations:

- ConEdison - High Density Polyethylene (HDPE) pipes were welded
- PS&G - Medium Density Polyethylene (MDPE) pipes were welded

Joints were produced under standard (based on the pipe manufacturer or gas company recommendations) and substandard conditions that may result in lower strength. A McElroy 28 hydraulic pipe welding machine was primarily used to produce the weld joints. Pipe data, welding parameters and the NDE results are presented in Table 2 and Table 3

Table 2 Welding Parameters and NDE Results for ConEdison Samples

Material	Pipe Type and Size	OD (in)	ID (in)	Area (in^2)	Condition	Temp (^{o}F)	Time (sec)	Fusion Pressure (psi)	Sample ID	NDE Results
Driscoplex 6800, PE 3408	6" Yellowstripe SDR11	6.625	5.42	11.39	Standard	475	85	30.7	T	low profile projection
Driscoplex 6800, PE 3408	6" Yellowstripe SDR11	6.625	5.42	11.39	Low P	475	85	10	V	defined ridge
Driscoplex 6800, PE 3408	6" Yellowstripe SDR11	6.625	5.42	11.39	Low T	375	85	30.7	S	sharp indentation w. offset slight line in it
Driscoplex 6800, PE 3408	6" Yellowstripe SDR11	6.625	5.42	11.39	High T	550	85	30.7	U	line
8100 Driscopipe, PE3408	8" SDR11	8.625	7.06	19.27	Standard	475	148	47	O	no line
8100 Driscopipe, PE3408	8" SDR11	8.625	7.06	19.27	High T	550	148	47	R	thin line
8100 Driscopipe, PE3408	8" SDR11	8.625	7.06	19.27	Low T	375	148	47	Q	slight line
8100 Driscopipe, PE3408	8" SDR10	8.625	7.06	19.27	Low P	475	148	14	P	no line
8100 Driscopipe, PE3408	8" SDR11	8.625	7.06	19.27	SuperLow P	475	148	n	N	ridge with defined peak
Driscoplex 6800, PE 3408	4" SDR11	4.5	3.68	5.25	Standard	480	85	manual	X	low profile projection
Driscoplex 6800, PE 3408	4" SDR11	4.5	3.68	5.25	High T	550	85	manual	Y	ridge with defined peak
Driscoplex 6800, PE 3408	4" SDR11	4.5	3.68	5.25	Low T	375	85	manual	W	ridge with thin line on the top
Driscoplex 6800, PE 3408	4" SDR11	4.5	3.68	5.25	Low P	480	85	10	Z	ridge

Table 3 Welding Parameters and NDE Results for PS & G Samples

Material	Pipe Type and Size	OD (in)	ID (in)	Area (in^2)	Condition	Temp (^{o}F)	Time (sec)	Fusion Pressure (psi)	Sample ID	NDE Results
Driscoplex 6500, PE2406	8" SDR13.5	8.625	7.35	16.014	Standard	425	220	30	C	no line
Driscoplex 6500, PE2406	8" SDR13.5	8.625	7.35	16.014	Low P	425	220	10	A	no line, very slight projection
Driscoplex 6500, PE2406	8" SDR13.5	8.625	7.35	16.014	High T	550	220	30	B	line
Driscoplex 6500, PE2406	8" SDR13.5	8.625	7.35	16.014	Low T	350	220	30	D	no line
Driscoplex 6500, PE2406	6" SDR13.5	6.625	5.67	11.76	Standard	425	75	26	I	no line
Driscoplex 6500, PE2406	6" SDR13.5	6.625	5.67	11.76	Low T	375	75	26	G	no line
Driscoplex 6500, PE2406	6" SDR13.5	6.625	5.67	11.76	High T	550	75	26	H	no line
Driscoplex 6500, PE2406	6" SDR13.5	6.625	5.67	11.76	High P	550	75	60	E	no line
Driscoplex 6500, PE2406	6" SDR13.5	6.625	5.67	11.76	Low P	425	75	10	F	no line
Driscoplex 6500, PE2406	4" SDR11.5	4.5	3.72	5.045	Standard	429	60	manual	L	ridge
Driscoplex 6500, PE2406	4" SDR11.5	4.5	3.72	5.045	Low T	350	60	manual	K	no line, slight projection
Driscoplex 6500, PE2406	4" SDR11.5	4.5	3.72	5.045	High T	550	60	manual	J	ridge
Driscoplex 6500, PE2406	4" SDR11.5	4.5	3.72	5.045	High P	429	60	90	M	slight line w. indentation

3.2 Inspection of Fusion Joint Samples

During this period, EWI evaluated each butt fusion joint using the non-destructive WZIM approach and the existing laboratory prototype pipe inspection system. The effect of the pipe material on the inspection parameters was established, and the settings were optimized for each of the selected pipe materials.

3.2 Tensile test

An Instron Series IX Automated Material Testing System was used for tensile testing. Testing was conducted according to the ASTM D 638 procedure, except specimen dimensions were modified as shown in Figure 1.

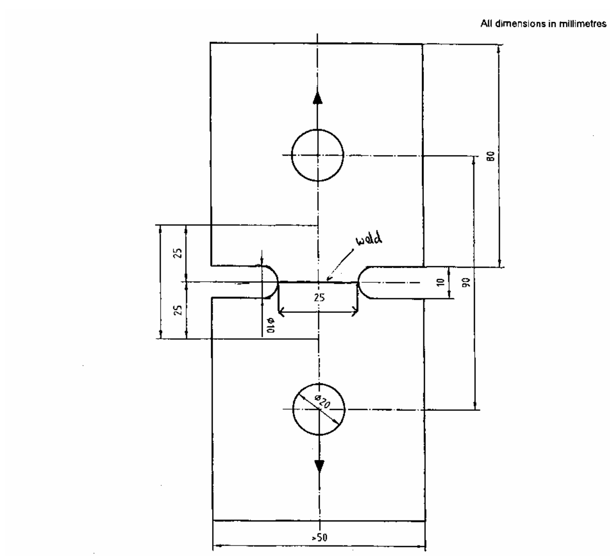


Figure 1 Tensile Test Specimen

In this specimen, the weld area section was reduced to cause failure initiation in the weld zone and not in parent material, as normally occurs with hot plate-welded PE dumb-bell specimens. The weakening of the weld area provides better differentiation in the joint quality assessment and reduced weld area in the tensile test is recommended specifically for the cases when normal test failure is achieved outside the weld area. Research data [(3)] shows that tensile tests conducted on specimens with reduced weld area are more sensitive in distinguishing between welds made under standard and non-standard conditions than other short-term destructive testing methods.

Three axially oriented specimens were cut from each welded pipe, with the weld located in the middle of the specimen. The test was performed at room temperature and a crosshead speed of 5 mm per min. Test results are shown in Table 4.

Table 4 Short-Term Mechanical Tensile Testing Results

Spec.	Spec.	Test	Initial Conditions			Final Conditions	Test	Maximum	Energy at	Energy at	Failure	Initial	Reduction	Elongation
ID	Orientation	Rate	Thick	Width	Length	Length	Temp.	Load	Break	Break/Area	Location	Area	in Area	
		(in/min)	(in)	(in)	(in)	(in)	(^{o}C)	(lbs)	(lb-in)	(lb/in)		(in^2)	(%)	(%)
R2	Transverse	0.2	0.803	0.934	1.466	1.906	24	2809	2295	3059.99184	Bond	0.750002	100	30.01
R1	Transverse	0.2	0.8	0.924	1.435	1.656	24	2903	2012	2721.861472	Bond	0.7392	100	15.40
A1	Transverse	0.2	0.699	0.946	1.395	2.510	24	1975	2808	4246.477148	Bond	0.661254	100	79.93
A2	Transverse	0.2	0.688	0.974	1.373	2.626	24	1837	2681	4000.823743	Bond	0.670112	100	91.26
B1	Transverse	0.2	0.685	1.024	1.389	2.265	24	2120	2135	3043.738595	Bond	0.70144	100	63.07
B2	Transverse	0.2	0.661	0.996	1.445	1.536	24	1726	453	688.0775751	Bond	0.658356	100	6.30
C1	Transverse	0.2	0.663	0.999	1.407	2.867	24	1941	2863	4322.57295	Bond	0.662337	100	103.77
C2	Transverse	0.2	0.662	1.026	1.349	2.601	24	1964	2747	4044.39262	Bond	0.679212	100	92.81
D1	Transverse	0.2	0.66	1.017	1.277	2.444	24	1980	2463	3669.43774	Bond	0.67122	100	91.39
D2	Transverse	0.2	0.671	1.077	1.318	2.712	24	2076	2798	3871.769432	Bond	0.722667	100	105.77
E1	Transverse	0.2	0.522	1.015	1.288	2.281	24	1604	1965	3708.736765	Bond	0.52983	100	77.10
E2	Transverse	0.2	0.511	0.98	1.295	2.469	24	1409	1821	3636.327329	Bond	0.50078	100	90.66
F1	Transverse	0.2	0.521	1.037	1.248	2.272	24	1585	1852	3427.871259	Bond	0.540277	100	82.05
F2	Transverse	0.2	0.512	1	1.260	2.272	24	1522	1696	3312.5	Bond	0.512	100	80.32
N1	Transverse	0.2	0.835	0.98	1.415	2.153	24	2830	3447	4212.391543	Bond	0.8183	100	52.16
N2	Transverse	0.2	0.799	1.022	1.400	2.157	24	3033	3728	4565.39363	Bond	0.816578	100	54.07
W1	Transverse	0.2	0.442	1.03	1.152	2.127	24	1467	1404	3083.952027	Bond	0.45526	100	84.64
W2	Transverse	0.2	0.44	1.063	1.155	1.988	24	1506	1386	2963.311383	Bond	0.46772	100	72.12
I1	Transverse	0.2	0.532	0.926	1.335	2.343	24	1479	1750	3552.347391	Bond	0.492632	100	75.51
H2	Transverse	0.2	0.522	1.015	1.353	2.157	24	1564	1587	2995.300379	Bond	0.52983	100	59.42
G1	Transverse	0.2	0.522	0.993	1.343	1.814	24	1492	1562	3013.431183	Bond	0.518346	100	35.07
I2	Transverse	0.2	0.529	1.058	1.316	2.292	24	1614	1953	3489.481527	Bond	0.559682	100	74.16
H1	Transverse	0.2	0.524	0.97	1.376	2.164	24	1480	1414	2781.931219	Bond	0.50828	100	57.27
G2	Transverse	0.2	0.52	1.082	1.150	2.252	24	1609	1719	3055.239585	Bond	0.56264	100	95.83
V1	Transverse	0.2	0.641	1.016	1.279	2.295	24	2160	2778	4265.603695	Bond	0.651256	100	79.44
V2	Transverse	0.2	0.637	1.003	1.289	2.268	24	2060	2484	3887.865446	Bond	0.638911	100	75.95
U1	Transverse	0.2	0.642	0.988	1.343	2.063	24	2118	2134	3364.359857	Bond	0.634296	100	53.61
U2	Transverse	0.2	0.636	1.02	1.336	2.275	24	2094	2564	3952.398569	Bond	0.64872	100	70.28
S1	Transverse	0.2	0.647	0.985	1.219	1.954	24	2065	2222	3486.611381	Bond	0.637295	100	60.30
S2	Transverse	0.2	0.65	0.992	1.211	2.113	24	2091	2254	3495.657568	Bond	0.6448	100	74.48
T1	Transverse	0.2	0.635	1.016	1.281	2.516	24	2152	3125	4843.759688	Bond	0.64516	100	96.41
T2	Transverse	0.2	0.637	0.975	1.295	2.486	24	2021	2604	4192.730347	Bond	0.621075	100	91.97
Y1	Transverse	0.2	0.451	1.063	1.282	2.231	24	1561	1728	3604.40789	Bond	0.479413	100	74.02
Y2	Transverse	0.2	0.453	1.028	1.297	2.329	24	1493	1658	3560.354232	Bond	0.465684	100	79.57
X1	Transverse	0.2	0.449	1.067	1.250	2.301	24	1543	1657	3458.690874	Bond	0.479083	100	84.08
X2	Transverse	0.2	0.458	1.092	1.251	2.471	24	1619	2103	4204.856279	Bond	0.500136	100	97.52
Z1	Transverse	0.2	0.434	1.054	1.265	2.016	24	1485	1527	3338.171897	Bond	0.457436	100	59.37
Z2	Transverse	0.2	0.451	0.903	1.250	2.010	24	1356	1344	3300.159851	Bond	0.407253	100	60.80
K1	Transverse	0.2	0.414	0.985	1.152	2.003	24	1134	1177	2886.289512	Bond	0.40779	100	73.87
K2	Transverse	0.2	0.413	0.908	1.157	1.903	24	1073	1022	2725.304263	Bond	0.375004	100	64.48
J1	Transverse	0.2	0.414	1.04	1.297	2.465	24	1235	1493	3467.577109	Bond	0.43056	100	90.05
J2	Transverse	0.2	0.416	1.046	1.304	2.509	24	1264	1571	3610.365495	Bond	0.435136	100	92.41
L1	Transverse	0.2	0.414	1.015	1.243	1.933	24	1182	1186	2822.398325	Bond	0.42021	100	55.51
L2	Transverse	0.2	0.413	0.991	1.226	1.983	24	1148	1220	2980.82256	Bond	0.409283	100	61.75
M1	Transverse	0.2	0.412	0.965	1.268	2.312	24	1095	1302	3274.812616	Bond	0.39758	100	82.33
M2	Transverse	0.2	0.419	0.981	1.234	2.378	24	1163	1424	3464.391457	Bond	0.411039	100	92.71
O1	Transverse	0.2	0.806	0.951	1.417	1.880	24	2853	2666	3478.120197	Bond	0.766506	100	32.67
O2	Transverse	0.2	0.794	0.992	1.341	1.885	24	2804	2152	2732.184935	Bond	0.787648	100	40.57
P1	Transverse	0.2	0.794	1.032	1.385	2.524	24	3086	4563	5568.654443	Bond	0.819408	100	82.24
P2	Transverse	0.2	0.782	1.003	1.388	2.206	24	2896	3388	4319.522252	Bond	0.784346	100	58.93
Q1	Transverse	0.2	0.828	0.999	1.288	1.780	24	2959	2956	3573.621931	Bond	0.827172	100	38.20
Q2	Transverse	0.2	0.785	1.013	1.336	1.838	24	2943	2923	3675.781717	Bond	0.795205	100	37.57

4.0 - RESULTS AND DISCUSSION

This report describes the first 12 month's progress of a project sponsored by the U.S. Department of Energy (DOE) National Energy Technology Laboratory (NETL) to develop a technique for the inspection of fusion joints in plastic pipe used as gas distribution pipelines. In order to thoroughly investigate this technology, this project brings together a combination of partners that have a proven track record in pipeline technology. The project team consists of EWI, a full-service provider of materials joining engineering services and NYSEARCH, an international consortium of pipeline companies that will provide project oversight and direction. EWI is the lead organization performing this award for NETL located in Morgantown, West Virginia.

Task 1.0 Research Management Plan

During the previous reporting period, the team created a Research Management Plan [(1)]. This document contains a work breakdown structure and supporting narrative that concisely summarizes the overall project. The plan is an integration of the technical and programmatic data into one document that details the technical objectives and technical approach for each task and subtask. The document also contains detailed schedules and planned expenditures for each task and all major milestones/decision points.

Task 2.0 Technology Status Assessment

During the previous reporting period, a Technology Status Report [(2)] was produced and presented to NETL that presents the status of existing pipeline non-destructive inspection technology that can be applied to the gas distribution pipeline. This report describes the current state-of-the-art technologies that are being developed, including the positive and negative aspects of each technology. Available options for in-situ non-destructive inspection of butt fusion joints in plastic pipe were identified.

Task 3.0 Validation of Inspection Method and Optimization of Testing Procedure

During the previous reporting period, EWI validated the WZIM for plastic natural gas pipe through the use of short-term destructive mechanical tests on plastic pipe joints. EWI examined welds of plastic natural gas pipe made under various standard and non-standard conditions and analyzed the correlation between the WZIM joint image and mechanical joint strength assessed by short term destructive tensile testing (STDT).

EWI initiated the validation of the WZIM non-destructive inspection procedure and optimization of inspection system parameters (power output, heating time, and distance) for specific plastic pipe types typically used in natural gas pipeline using existing EWI laboratory prototype inspection system. The validation program shall include the following sub-tasks:

Subtask 3.1 Preparation of Fusion Joint Samples

During the previous reporting period, EWI and NYSEARCH identified the most commonly used plastic pipe materials and sizes used by gas distribution companies, NYSEARCH-members. As shown in Table 1, Driscopipe 8100, Driscoplex 6500 and 6800 were the most commonly used materials. 101, 152 and 203 mm (4, 6 and 8 inch) diameters were determined to be the most commonly used sizes for these grades.

Twenty-six fusion joint samples were prepared under the cost-share portion of this project, which was funded separately by NYSEARCH. Six of the twenty-six samples were welded under standard conditions. Table 1 shows the material characteristics of the samples that were exposed to STDT.

Subtask 3.2 Inspection of Fusion Joint Samples

Weld zone images of standard joints and joints with typical defects were developed and the inspection results are reported in Table 2 and Table 3.

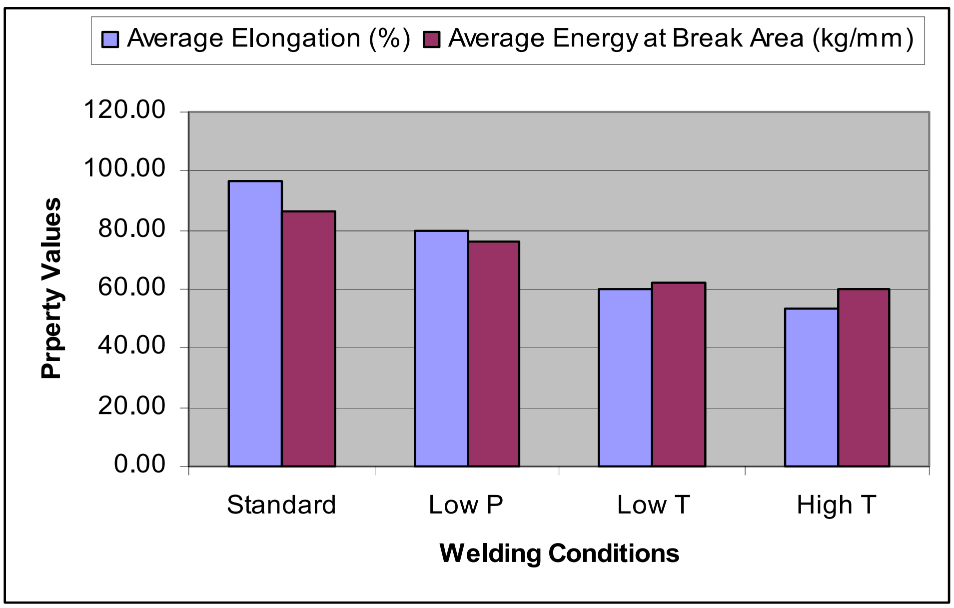
Subtask 3.3 Correlation of Inspection and Mechanical Joint Test Results

During the previous reporting period, the strength of each fusion joint was assessed with mechanical tensile tests. The test data was analyzed and correlated to the welding conditions under which the joints were produced. EWI conducted preliminary analysis of the data and compared the results of short term destructive tensile testing (STDT) to the WZIM inspection results. *Since WZIM results are based on visual examination (not laser scan results) and the long-term testing data is not currently available, the following data analysis should be considered preliminary.*

Based on STDT results, as shown in Figure 2 through Figure 7, the WZIM accurately detected all seals with reduced strength. Several joints made under substandard conditions were detected by the WZIM, which did not show a reduced strength during the STDT. It appears that the WZIM inspection is more sensitive in distinguishing joints made under substandard conditions than STDT. This can be explained by the fact that STDT, while providing an initial indication of the weld quality, is not sensitive enough to be used as a final means for evaluating the effect of flaws in plastic welds, including those resulted from substandard welding conditions. Also, STDT may not directly correlate with long-term strength of the joint under static and fatigue loading.

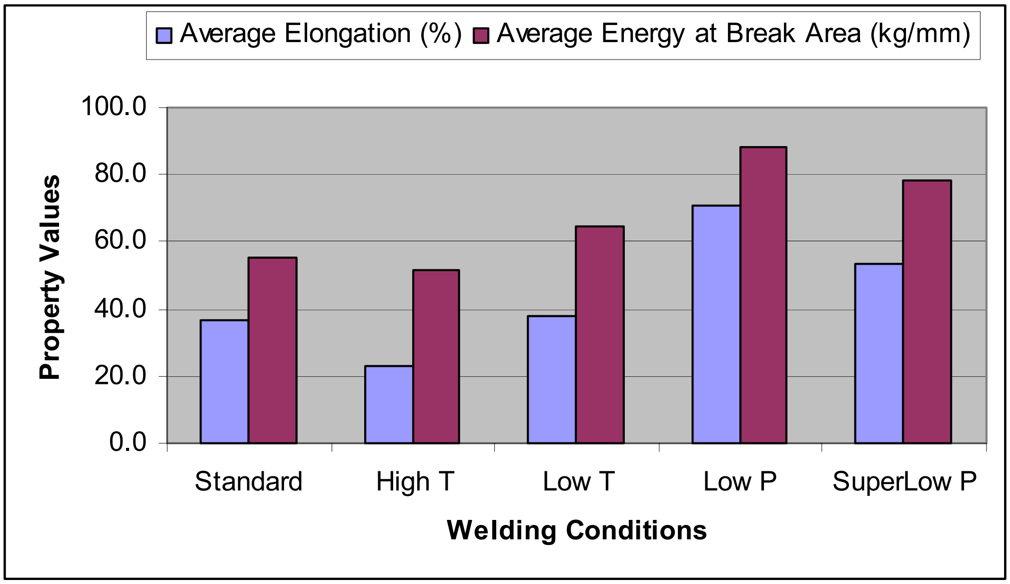
Another factor that should be considered while analyzing the STDT results, is that PE has good weldability - its ability to produce sound welds in a wide range of welding parameters and to tolerate variations from the recommended settings. However different PE grades may show different process parameters variation tolerance and these factors should be considered as the results are being analyzed.

For example, pipe grades of medium density PE and 8100 grade of high density PE both demonstrated the ability to produce excellent welds at a lower fusion pressure range, based on their high melt flow index. However, the 8100 grade appears to be more sensitive to the excessive heating (Condition "High Temperature") than other grades. High temperature effects are more detrimental to larger pipes with thicker walls. These pipes are heated for longer times than small pipes, and as a result the material is exposed to an elevated temperature for a longer period. Based on this, thermal decomposition of the polymer is much likelier in large pipes, and this is reflected in both, tensile test and WZIM, results.



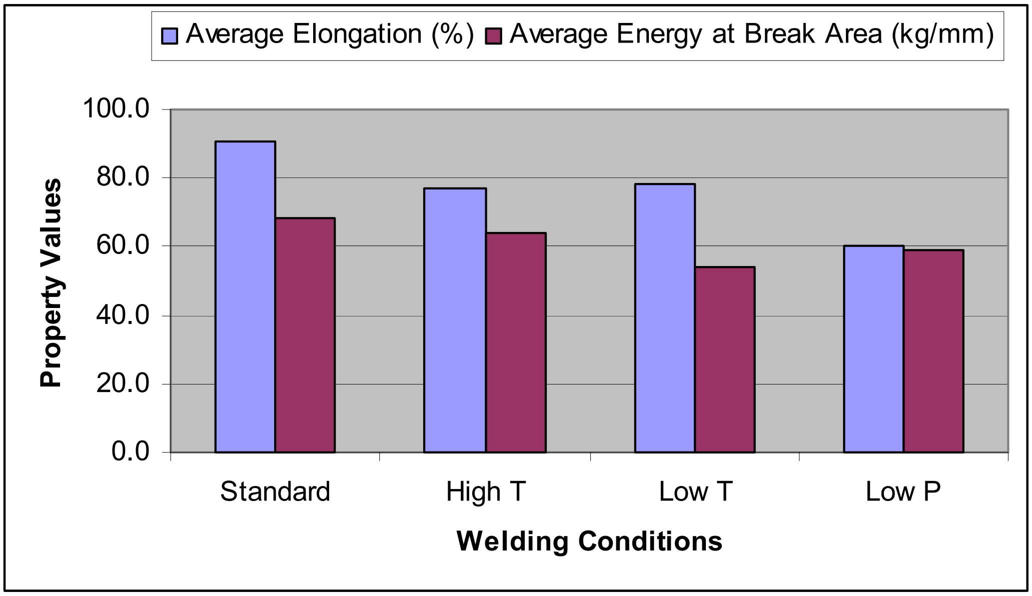
Condition	Average Elongation (%)	Average Energy at Break Area (kg/mm)	WZIM Observation	WZIM Prediction
Standard	96.41	86.4	Low profile projection	Good
Low P	79.44	76.1	Defined ridge	Uncertain
Low T	60.30	62.2	Sharp indentation with slight offset line	Reduced
High T	53.61	60.0	Line	Reduced

Figure 2 Driscoplex 6800, PE 3408, 152mm (6 in.) Yellowstripe SDR11



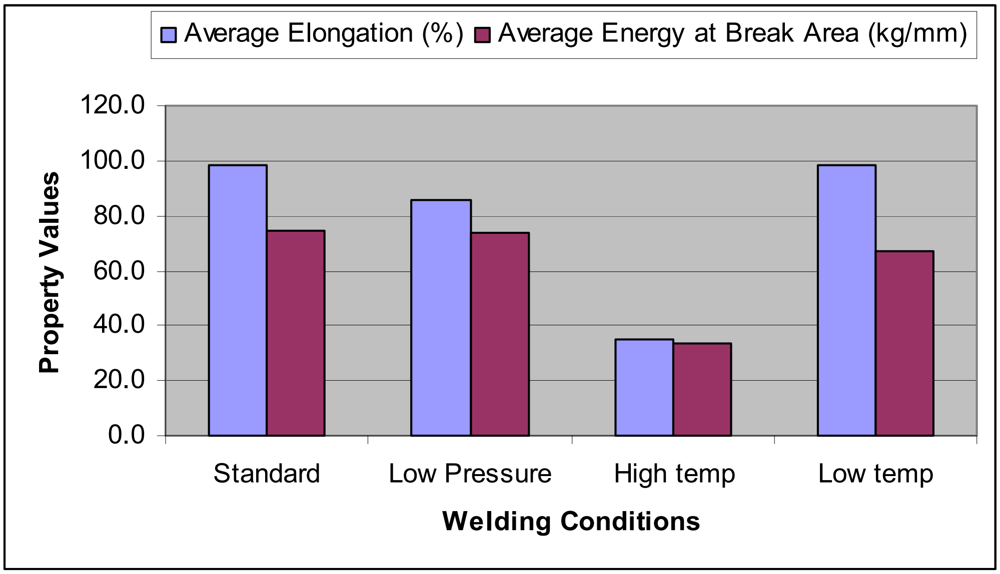
Condition	Average Elongation (%)	Average Energy at Break Area (kg/mm)	WZIM Observation	WZIM Prediction
Standard	36.6	55.4	Very slight line	Uncertain
High T	22.7	51.5	Thin line	Reduced
Low T	37.9	64.6	Slight line	Reduced
Low P	70.6	88.2	No line	Good
SuperLow P	53.1	78.3	Ridge with defined peak	Uncertain

Figure 3 8100 Driscopipe, PE3408 203mm (8 in.) SDR11



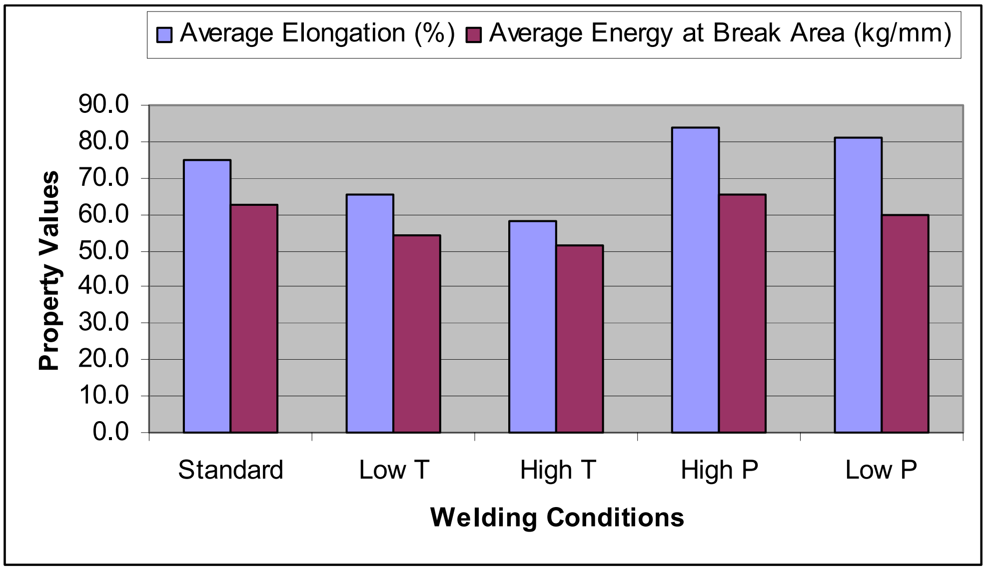
Condition	Average Elongation (%)	Average Energy at Break Area (kg/mm)	WZIM Observation	WZIM Prediction
Standard	90.8	68.3	Low profile projection	Good
High T	76.8	63.9	Ridge with defined peak	Uncertain
Low T	78.4	53.9	Ridge with thin line on the top	Reduced
Low P	60.1	59.2	Ridge	Uncertain

Figure 4 Driscoplex 6800, PE 3408, 101mm (4 in.) SDR11



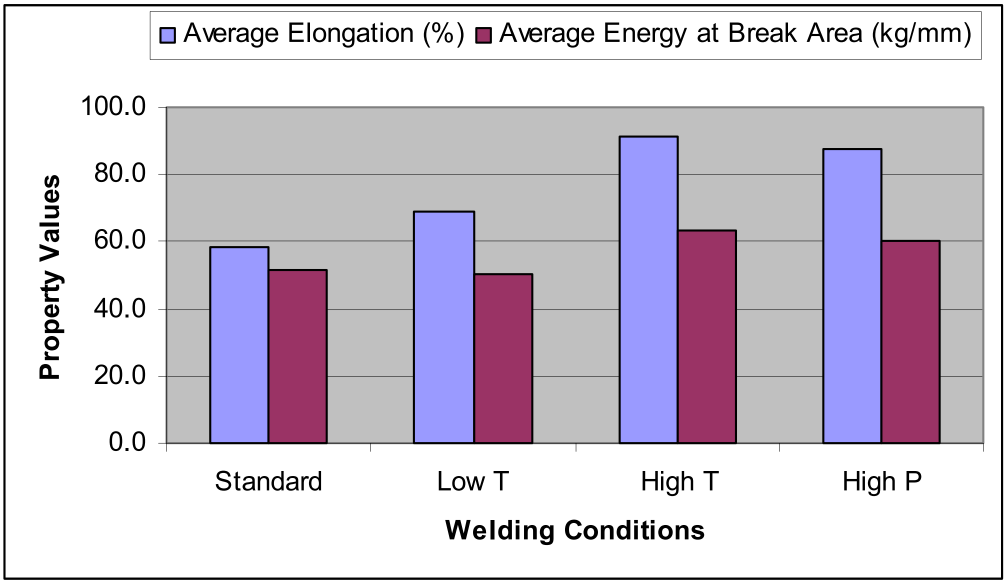
Condition	Average Elongation (%)	Average Energy at Break Area (kg/mm)	WZIM Observation	WZIM Prediction
Standard	98.3	74.6	No line	Good
Low Pressure	85.6	73.5	No line, very slight projection	Good
High temp	34.7	33.3	Line	Reduced
Low temp	98.6	67.2	No line	Good

Figure 5 Driscoplex 6500, PE2406, 203mm (8 in.) SDR13.5



Condition	Average Elongation (%)	Average Energy at Break Area (kg/mm)	WZIM Observation	WZIM Prediction
Standard	74.8	62.8	No line	Good
Low T	65.4	54.1	No line	Good
High T	58.3	51.5	No line	Good
High P	83.9	65.5	No line	Good
Low P	81.2	60.1	No line	Good

Figure 6 Driscoplex 6500, PE2406, 152mm (6 in.) SDR13.5



Condition	Average Elongation (%)	Average Energy at Break Area (kg/mm)	WZIM Observation	WZIM Prediction
Standard	58.6	51.7	Ridge	Uncertain
Low T	69.2	50.0	No line, slight projection	Good
High T	91.2	63.1	Ridge	Uncertain
High P	87.5	60.1	Slight line with indentation	Reduced

Figure 7 Driscoplex 6500, PE2406, 101mm (4 in.) SDR11.5

Task 4.0 Method Verification using Long Term Destructive Testing

During this reporting period, EWI initiated the task that will verify the sensitivity of the non-destructive inspection results and the STDT through long-term elevated temperature creep rupture destructive testing (LTDT) on specimens cut from selected welds. Long term testing was performed at The Welding Institute (TWI). Three specimens were cut from welds that failed the WZIM inspection method and six specimens were cut from welds that passed. Of these specimens, three were taken from locations where local reheating took place and three from locations that were not subjected to local reheating.

At the point of writing this report, TWI has reported that the LTDT has been concluded and the test results are being analyzed. LTDT data will be correlated with parameters used to produce the joints and results of the non-destructive inspection and STDT data. Based on this analysis, EWI will develop preliminary conclusions regarding the sensitivity and reliability of the WZIM inspection method and also in determination of whether performing local reheating on a quality weld has a detrimental effect on the long-term performance of the weld.

Task 5.0 Specification of User Requirements for Prototype Image Recognition System

During the previous reporting period, a draft document was created by EWI with NYSEARCH cooperation that outlines operational, performance and pass/fail requirements for the prototype WZIM inspection system. User requirements include operational and performance requirements of a method for butt fusion joint inspection in gas distribution plastic pipelines under field conditions. These conditions shall define requirements for assignment of pass/fail rating of inspected joint.

During this period, the User Requirements Document was updated as system performance details were established. Next period, this document is expected to be modified and updated as field testing is initiated.

Task 6.0 Development of Image Recognition Inspection System

During the previous reporting period, EWI initiated the development of a non-destructive laser based plastic pipe inspection system and associated software, which can assign a pass/fail rating to the inspected joint based on data collected from the laser scan of the weld area.

During this reporting period, all hardware has been procured, the software has been developed and the system has been integrated.

Subtask 6.1 Development of Laser Based Inspection Hardware

During the previous period, two laser sensor approaches (spot and line) were investigated and evaluated on sample pipe welds. The laser spot sensor offers sub-micron resolution and is capable of distinguishing smaller items than the line sensor. The main drawback of the spot sensor is that only one dimension (one spot) can be determined at a specific time. In order to map the complete surface of the weld zone, the sensor would need to be moved in both X and Y directions. With this approach, the complexity of the software required to generate the topographical map of the surface increases as well as the inspection cycle time. Based on these drawbacks, a laser line approach was selected.

A laser line sensor uses hundreds of spots to form a line across the part surface. The resolution of the laser line sensors is in the micron range and the laser line can be varied to profile different surface lengths. The primary advantage of laser line sensors is that measurements are made in two dimensions, which decreases the degrees of freedom (DOF) required to map the surface of the weld. Three competing laser line sensors are being evaluated to determine the best approach for this application. The internal imager chip, data format and resolution vary between sensors.

Two sensors, built by the same manufacturer, are identical except the imager chip. Two distinctly different technologies are employed for capturing images digitally, CCD (charge coupled device) and CMOS (complimentary metal oxide semiconductor). Each image sensor has unique strengths and weaknesses, which make each sensor suited better for specific applications. CCD sensors typically create high quality (resolution) images with little noise. CMOS, a newer and faster method, typically offers lower quality (resolution) images and is more susceptible to noise than CCD. The third laser sensor uses CMOS technology, which consumes less power, is less expensive to manufacture and offers the fastest data transfer rate of the sensors being evaluated.

Laser line sensors are available in a variety of sizes (laser line lengths) and weld samples are being evaluated at two laser line lengths. Laser line length ultimately determines laser sensor resolution.

Hardware for positioning the laser sensor and the heating element was evaluated and acquired. Both the laser sensor and the heating element must be designed to work independently and allow for height adjustability from the pipe surface. System hardware selection was finalized and components have been purchased and received, including motion control, positioning slide assembly and fixturing. Hardware for the prototype system is currently being assembled.

During this reporting period, three laser line sensors were evaluated and the appropriate sensor model was purchased. The laser type most suited for this application was determined to be a laser line sensor with a 5 mm line length and was the MT20 series manufactured by Meta-MVS.
.

The motion system, which is responsible for moving the heating element into position and moving the laser sensor at a constant speed over the weld zone area on the pipe surface, was evaluated and acquired. The motion system includes a linear slide assembly, a motor and amplifier to move the linear slide, and positioning scales (Figure 8 and Figure 9). The requirements of the system state that both the laser sensor and the heating element must be designed to work independently and allow for height adjustability from the pipe surface. Key factors involved in selection of motion system components include weight, rigidity and performance. The weight of the system had to be kept under the specified amount, yet still allow for ruggedness during field trials. Since the user must manually place the system on and off the pipe, it had to be designed for easy portability and rigidity to withstand handling. Most importantly, the motion system needed to maintain solid, repeatable performance. This is due to the sensitivity of the laser measurements requiring a smooth scanning motion so as not to induce error in the topographical map. Once completed, the motion system had to be integrated with the software program. The software involved in the system at this level is responsible for controlling the motion and laser system. System hardware was selected, assembled and tested on calibrated samples in the lab.

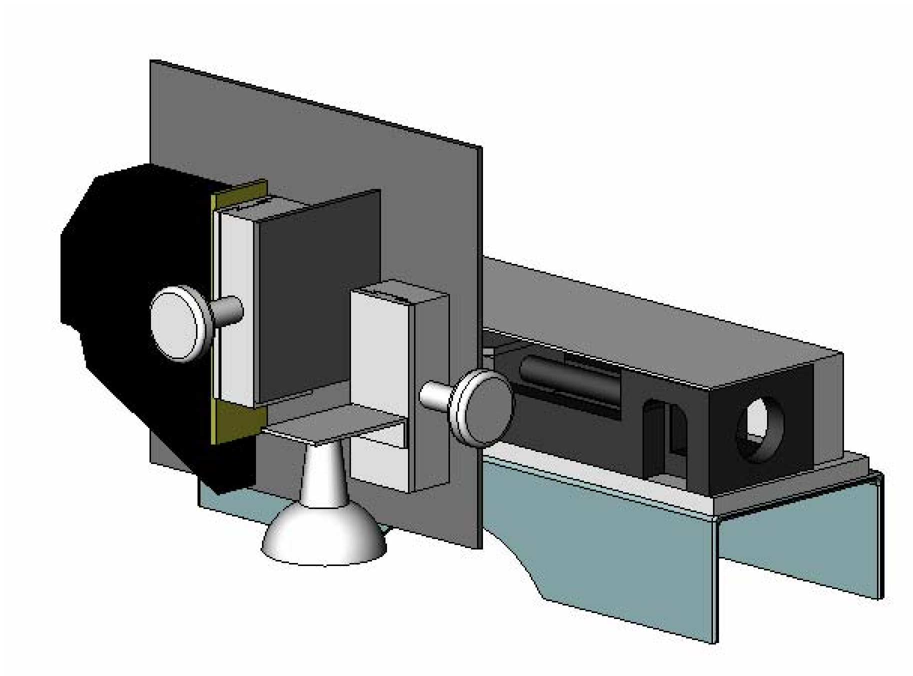


Figure 8 Motion System Hardware Components Drawing

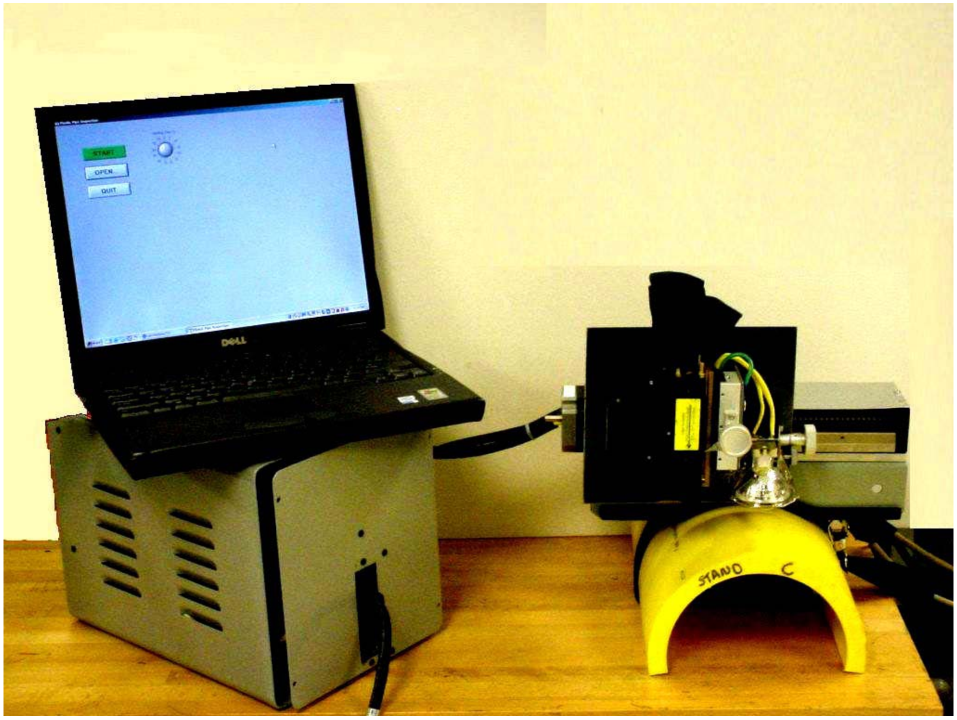


Figure 9 WZIM Inspection Equipment (without protective cover)

Subtask 6.2 Development of Inspection System Software

During the previous reporting period, EWI was tasked with developing software for analysis of scanned weld data and measurement of weld zone characteristics including weld zone shape and size and the presence of weld bond line. A software program was written to acquire data from the laser sensor and package the data into a standard file format. Depending on the type of laser sensor chosen, the software will need to be tailored to accept the format of the data from the laser sensor. There are two sub tasks within the development of inspection system software task. The first task involved gathering the data from the laser sensor and positioning it within a file that is easily readable by the computer or person. This task involves time management to ensure the data is captured as fast as possible in preparation for analysis by the inspection algorithm that will be fully developed in the next period.

Development began on an algorithm for analyzing the laser data files and for assessing the integrity of the weld zone. Currently, ten different measurements are required in order to accurately assess the weld zone. Several of the measurements have been incorporated into the inspection algorithm and are currently being tested. This first measurement algorithms form the basis of future measurements that will be incorporated into the algorithm within the next task.

During this reporting period, the software program executes the weld zone evaluation algorithms, which determine the integrity of the weld along with controlling the motion and laser sensor hardware,. EWI was tasked with developing software for analysis of scanned weld data and measurement of weld zone characteristics including weld zone shape and size and the presence of weld bond line. There are four sub tasks within the development of inspection system software. The first task involved the software developed for controlling motion and laser hardware. The second task involved gathering the data from the laser sensor and positioning it within a file that is easily readable by the computer or person. A software program was written to acquire data from the laser sensor and package the data into a standard file format. This task involves time management to ensure the data is captured as fast as possible in preparation for analysis by the inspection algorithm. The third task involved development of the inspection algorithm. At least ten different measurements are required in order to accurately assess the weld zone. The series of measurements were all evaluated on known samples in the lab. Again, large amounts of data are being manipulated so time conservation was a priority. The last task involved designing the user interface (UIR) for ease of use and display of inspection results. The UIR is the point of interaction between the operator and the WZIM system (Figure 10). It displays the PASS, FAIL or MARGINAL rating to each inspected weld zone and generates both a report and a text file including all measurement data (Appendix). The software program was designed to run in an Automatic or Manual mode. Automatic mode only requires the user to position the system on the pipe and press a START button on the UIR. Manual mode is better reserved for system diagnostics and more advanced users.

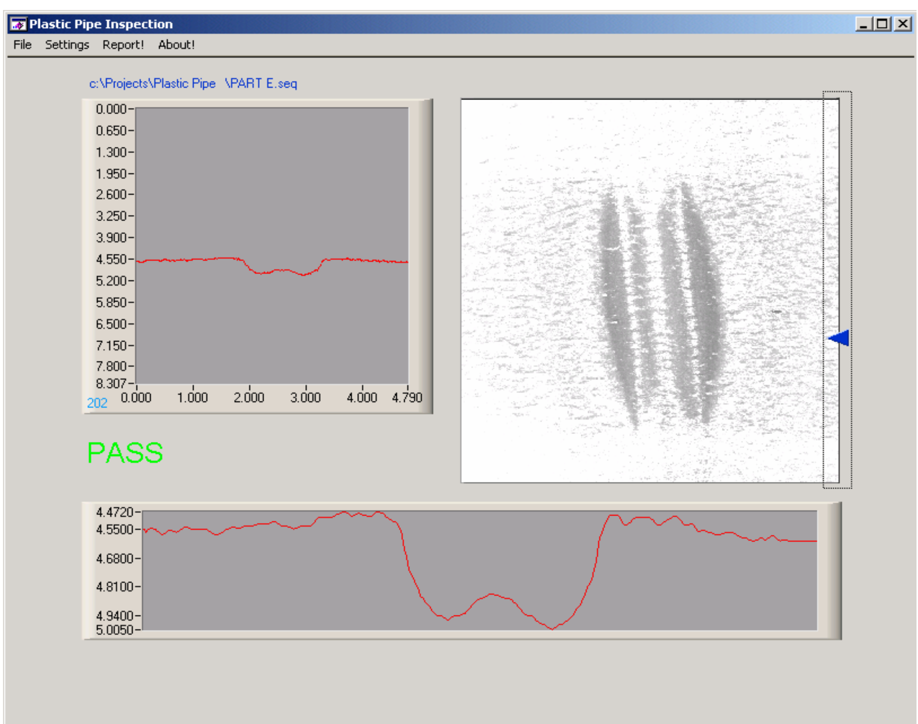


Figure 10 Software Inspecting Weld Zone

During the next reporting period, testing and refinement of the algorithm for analyzing the laser data files and for assessing the integrity of the weld zone will continue along with field testing.

Subtask 6.3 Integrate and Calibrate Laser Inspection Hardware and Software

During this reporting period, EWI integrated the inspection system hardware and software. The system was calibrated and extensively tested using pipe joints provided by gas distribution companies.

During the next reporting period, the system shall be modified based on testing results to optimize performance discovered during the field testing program.

Task 7.0 Development of Field Test Program

During the reporting period, development of the field test program was initiated. Table 5 shows the material properties and parameter characteristics of samples that were joined at Con Edison in August 2004. In preparation of the samples, the operator used visual inspection to obtain proper rollback for most samples. To produce over-heated and under-heated samples on the 12 inch pipe, heating time was held constant while the heating temperature was manipulated to produce sub-standard joints. All pipe samples were Performance Pipe 6800 except for Sample #10, which was 8100.

Table 5 WZIM Pipe Samples at Con Edison

No.	Size (in.)	Condition	Temp. (°F)	Pressure (psi)	Heat Time (min)	Comments
1	2	Standard	475-480	Normal	Cool to touch	Manual- lock in pressure – roll back 1/8”(+/-)
2	2	Low P	475-480	Low	Cool to touch	Manual- lock in pressure – roll back 1/8”(+/-)
3	2	High P	475-480	High	Cool to touch	Manual- lock in pressure – roll back 1/8”(+/-)
4	2	Low T	347-352	Normal	Cool to touch	Manual- poor roll back
5	4	Super Low P	501-510	40	--	Inconsistent bead – alignment is off
6	4	Super Low P	501-510	40	--	Used longer pipe section – alignment okay
7	6	Standard	501-510	230	--	
8	6	Low P (50%)	501-510	115	--	
9	6	Low T	350	230	--	
10	8	Super Low P	500	230	--	
11	12	Standard	480	600	1.46	
12	12	Super Low P	480	200	1.34	
13	12	High T	550	600	1.46	
14	12	Low T	350	600	1.46	

Table 6 Testing Machine Matrix for Field Testing Program

No.	Size (in.)	Machine Type	Machine Brand
1-4	2	Hydraulic	MacElroy
5-10	4, 6, 8	Manual	Connectra
11-14	12	Hydraulic	MacElroy

During the next reporting period, the field testing program will be further developed and refined in cooperation with the gas distribution companies.

Task 8.0 Field Test Preparation

No activity was conducted for this task during this reporting period, as development is scheduled to begin in October of 2004.

Task 9.0 Prototype Field Testing

No activity was conducted for this task during this reporting period, as development is scheduled to begin in February of 2005.

Task 10.0 Field Data Analysis & Optimization of Specifications / Inspection Guidelines

No activity was conducted for this task during this reporting period, as development is scheduled to begin in May of 2005.

5.0 - CONCLUSIONS

(1) WZIM can accurately detect all the seals that showed reduced strength during the STDT.

(2) WZIM inspection is more sensitive in distinguishing joints made under substandard conditions than STDT.

(3) All hardware required for WZIM has been thoroughly evaluated and purchased.

(4) The software for acquiring the laser sensor data has been written.

(5) The prototype system has been integrated and appears to be functioning appropriately.

(6) The initial prototype development activity is complete and ready for field testing to begin.

6.0 - REFERENCES

(1) Savitski, A., and Coffey, J., "Inspection of Fusion Joints in Plastic Pipe – Research Management Plan," Report to National Energy Technology Laboratory, U.S. Department of Energy, DOE Award No.: DE-FC26-02NT41882, Edison Welding Institute, October 2003.

(2) Savitski, A., and Fabiano, A., "Inspection of Fusion Joints in Plastic Pipe – Technology Status Assessment," Report to National Energy Technology Laboratory, U.S. Department of Energy, DOE Award No.: DE-FC26-02NT41882, Edison Welding Institute and NYSEARCH, November 2003.

(3) Chipperfield, F. and Troughton, M., "Comparison of Short-Term Coupon Tests for Assessing the Performance of Butt Fusion Welds in Polyethylene Pipes," Proceedings of 1999 International Plastic Pipe Symposium

7.0 - BIBLIOGRAPHY

(1) Savitski, A., and Coffey, J., “Inspection of Fusion Joints in Plastic Pipe – Research Management Plan,” Report to National Energy Technology Laboratory, U.S. Department of Energy, DOE Award No.: DE-FC26-02NT41882, Edison Welding Institute, October 2003. This plan contains a concise summary of the technical objectives and approach for each task. The document also contain detailed schedules and planned expenditures for each task and all major milestones and decision points for the two year project duration.

(2) Savitski, A., and Fabiano, A., “Inspection of Fusion Joints in Plastic Pipe – Technology Status Assessment,” Report to National Energy Technology Laboratory, U.S. Department of Energy, DOE Award No.: DE-FC26-02NT41882, Edison Welding Institute and NYSEARCH, November 2003. This report presents the current state-of-the-art of plastic pipe inspection, including the positive and negative aspects of using each technology. Available options for in-situ non-destructive inspection of butt fusion joints in plastic pipe are identified.

8.0 - LIST OF ACRONYMS

PE	Polyethylene
EWI	Edison Welding Institute
WZIM	Weld Zone Inspection Method
QA	Quality Assurance
HDPE	High Density Polyethylene
MDPE	Medium Density Polyethylene
DOE	Department of Energy
NETL	National Energy Technology Laboratory
STDT	Short Term Destructive Testing
LTDT	Long Term Destructive Testing
TWI	The Welding Institute
CCD	Charge Coupled Device
CMOS	Complimentary Metal Oxide Semiconductor