February 14, 1997

L972820TA

Mr. Charlie Mauldin
John Gandy Corporation
One Texas Commerce Plaza
200 River Pointe Drive, Suite 310
Conroe, Texas 77304-2817

REPORT ON EVALUATION OF CERAMIC COATINGS ON C276

Dear Mr. Mauldin:

Presented herein are the results of the tests conducted on JGC2012 ceramic coatings applied to C276 by CLI *International*, Inc. (CLI) for John Gandy Corporation. These tests involved abrasion resistance of the JGC2012 ceramic coating, and measurements of general and galvanic corrosion behaviors by electrochemical techniques. The tests were conducted under your purchase order number P97003.

SUMMARY

Electrochemical measurements were conducted on C276 specimens which were coated with JGC2012 completely (100 percent coated), and partially (30, 60 and 100 percent coating removed). The galvanic corrosion tests were conducted between these C276 specimens with varying degrees of coatings removed and L80 carbon steel specimens.

The impact abrasion tests conducted on JGC2012 ceramic coatings on C276 as per ASTM D4060-90 provided a wear index of 0.08 (coating to substrate).

The C276 electrode, coated 100 percent with JGC2012 ceramic, provided an extremely small general corrosion rate of 0.002 mpy ($5x10^{-5}$ mmpy). This corrosion rate increased to 0.07 and 0.16 mpy ($2x10^{-3}$ and $4x10^{-3}$ mmpy) as 30 and 60 percent of the coating was removed, respectively. The 60 percent coating removal condition was similar in terms of corrosion rate to that of the uncoated electrode.

The galvanic corrosion rate measured for the JGC2012 ceramic coated C276 electrode (100 percent) coupled to L80 carbon steel was 0.01 mpy ($3x10^{-4}$ mmpy). The measured galvanic

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corrosion rates increased to 6 and 9 mpy (0.15 and 0.23 mmpy) as 30 and 60 percent of the coating was removed, respectively. However, these galvanic corrosion rates were much smaller than that measured between an uncoated C276 electrode and an L80 electrode (19 mpy; 0.48 mmpy).

EXPERIMENTAL PROCEDURES

TEST MATERIALS AND ENVIRONMENTS

The electrodes used for the electrochemical tests were 0.25 inch (0.635 cm) diameter by 1 inch (2.54 cm) long rods machined from C276 and L80 carbon steel. The C276 electrodes were tested under completely and partially coated conditions. The coating on C276 specimens was a ceramic type, named JGC2012, applied by Global Industrial Coatings (Rolla, Missouri). The partially coated conditions (70 and 40 percent coated) were achieved by simply removing the coatings to expose the substrate to the desired levels. The test matrix selected is provided in Table 1. The electrochemical tests were conducted in 100,000 ppm NaCl environments with near neutral pH values at 175 F.

The abrasion resistance of the JGC2012 ceramic coatings on C276 was tested as per ASTM D4060-90 by Technical Services Laboratories, Inc. (Springfield, Missouri).

TEST APPARATUS AND PROCEDURES

The experimental set-up, used for the electrochemical tests, consisted of a five neck, one liter glass vessel (EG&G PARC K47 corrosion cell). A saturated calomel electrode (SCE) was used as the reference electrode while a platinum wire served as the counter electrode.

The test solution was prepared and brought to the test temperature of 175 F. The electrodes were introduced to the environment at test temperature and allowed to stabilize. The electrochemical corrosion rates for the coated (completely and partially) C276 and L80 materials were measured by conducting potentiodynamic polarization scans per ASTM G59. These scans were conducted at 0.25 mV/sec. The electrodes were allowed to stabilize after the polarization scans and the corrosion potentials were recorded. The galvanic corrosion between the coated C276 (100, 70, 40 and 0 percent coated) and L80 materials was monitored by coupling the two electrodes via a zero resistance ammeter per ASTM G71. The galvanic current was recorded until stable values were reached (3 to 4 hours) along with the equilibrium potential. This equilibrium potential refers to the potential at which the total oxidation rate equals the total reduction rate of the coupled system.

At the end of the exposures, the test electrodes were retrieved, cleaned and examined for the type of corrosion (localized or general).

RESULTS AND DISCUSSION

IMPACT ABRASION TEST DATA

The impact abrasion test results for the JGC2012 ceramic coatings on C276 provided by Technical Services Laboratories, Inc. are included in Appendix I. These data provided a wear index of 0.08 and wear cycles (coated to substrate) of 5000. The wear index refers to the loss in weight in milligrams per 1000 cycles of abrasion under a specific set of test conditions. The wear cycles is the number of cycles of abrasion required to wear a coating of specified thickness to the test plate under a specific set of test conditions.

CORROSION RATES

The corrosion rates measured for L80, and C276 electrodes with varying levels of coating removed are provided in Table 2. The measured corrosion rates for the L80 electrodes ranged from 17 to 25 mpy (0.43 to 0.64 mmpy) giving an average value of 20 mpy (0.51 mmpy). The 100 percent coated C276 electrodes gave an extremely small corrosion rate of 0.002 mpy ($5x10^{5}$ mmpy). This corrosion rates increased to 0.07 mpy ($2x10^{-3}$ mmpy) and to 0.16 mpy ($4x10^{3}$ mmpy) as the coating was removed by 30 and 60 percent, respectively (see Table 2). The corrosion rate measured at 60 percent coating removed condition, was similar to that obtained at completely uncoated condition.

GALVANIC CORROSION RATES

The galvanic corrosion rates measured for coated C276 electrodes coupled to L80 electrodes are detailed in Table 3. The highest and lowest galvanic corrosion rates of 19 mpy (0.48 mmpy) and 0.01 mpy ($3x10^{-4}$ mmpy) were measured when L80 was coupled to completely uncoated and coated C276 electrodes, respectively. The measured galvanic corrosion rates between C276 and L80 increased to 6 and 9 mpy (0.15 and 0.23 mmpy) as 30 and 60 percent of the coating was removed, respectively (see Table 3). However, even at the 60 percent coating removed condition, the measured galvanic corrosion rate was about one half of that measured between the uncoated C276 and L80 electrodes.

The post exposure examination of the electrode surfaces indicated the absence of localized or pitting corrosion on L80 electrodes when the C276 electrodes were coated to some extent. However, the L80 electrode suffered pitting corrosion when it was coupled to an uncoated C276 electrode.

CONCLUSIONS

Based on the testing program described herein, the following conclusions were made:

1. The impact abrasion tests conducted on JGC2012 ceramic coatings on C276 as per ASTM D4060-90 provided a wear index of 0.08 and wear cycles of (coating to substrate) 5000.

2. The general corrosion rate measured for the electrode with 100 percent of JGC2012 ceramic coating was extremely small (0.002 mpy). This corrosion rate increased to 0.07 and 0.16 mpy as 30 and 60 percent of the coating was removed, respectively. The corrosion rates measured at 60 percent coating removed and uncoated conditions were similar.

3. The galvanic corrosion rate measured for the JGC2012 ceramic coated electrode coupled to L80 carbon steel was extremely small (0.01 mpy). The measured galvanic corrosion rates between L80 and coated C276 increased to 6 and 9 mpy as 30 and 60 percent of the coating was removed, respectively. However, these galvanic corrosion rates were much smaller than that measured for an uncoated C276 electrode coupled to a L80 electrode (19 mpy).

Thank you for the opportunity to provide testing services and technical support to John Gandy Corporation. If you have any questions regarding this report or need further assistance, please contact the undersigned.

Very truly yours,

D. Abayarathna

Dr. Dharma Abayarathna
Senior Scientist

Dr. Michael S. Cayard
Vice President

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TABLE 1

Test Matrix

Test No.	JGC2012 Ceramic Coated C276	
	Coating Coverage (%)	Exposed Substrate (%)
1	0	100
2	100	0
3	70	30
4	40	60

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TABLE 2

Corrosion Rates from Electrochemical Data

Material	Eccor (V vs SCE)	Icorr ($\mu A/cm^2$)	Corrosion Rate (mpy)
L 80	-0.810	41	19
L 80	-0.795	38	18
L 80	-0.805	56	25
L 80	-0.818	38	17
C 276 (100% Uncoated)	-0.210	0.330	0.150
C 276 (100% Coated)	-0.358	0.004	0.002
C 276 (70% Coated)	-0.249	0.160	0.071
C 276 40% Coated	-0.321	0.350	0.161

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TABLE 3

Galvanic Corrosion Data

Galvanic Couple	Anode	Cathode	Equilibrium Potential (V vs SCE)	Galvanic Current Density ($\mu A/cm^2$)	Galvanic Corrosion Rate (mpy)	Corrosion Type
L 80 & C 276 (100% Uncoated)	L 80	C 276	-0.765	41	19.13	Pitting
L 80 & C 276 (100% Coated)	L 80	C 276	-0.790	0.02	0.01	GC†
L 80 & C 276 (70% Coated)	L 80	C 276	-0.777	12	5.60	GC
L 80 & C 276 (40% Coated)	L80	C 276	-0.777	19	8.87	GC

† - GC = general corrosion

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UPON FUTURE CORRESPONDENCE
REFER TO REPORT NUMBER

Material GRAY PAINT **Test Report No.** E-2194
Customer CLI INTERNATIONAL, INC **Address** HOUSTON, TX
Purchase Order No. **File No.** T-999 **Specification**
Date Sample Submitted **Date Sample Received** JANUARY 15, 1997

The laboratory has completed examination of one gray taber test panel. The test panel was subjected to conditions as described in **ASTM D-4060-90** and **Federal Standard 141C, Method 6192.1**. The test apparatus consisted of a Taber Abraser and assessories, No. CS-17 abrasive wheels, and a 1000 gram load weight. The resurfacing interval, using an S-11 abrasive disk, was every 500 cycles. Results of our analysis are as follows:

Product JGC-2012

Wear Index 0.08

Weight Loss:

500 cycles.....39.7 mg

1000 cycles.....81.6 mg

2000 cycles.....137.6 mg

3000 cycles.....205.6 mg

4000 cycles.....321.5 mg

5000 cycles.....433.5 mg

Wear Cycles:
Coating to Substrate 5000

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Analyzed by: G.D. Ezell **Reported By:** G. D. Ezell

Approved by: R. E. Doughty **Date:** January 16, 1997
R. E. Doughty, Laboratory Director