

Studying The Effect of Low Temperature on Adhesion Strength of Internal Lining Coating for Steel Liquid Gas Storage Tanks

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Abstract:

Metal storage tanks for liquid gas are unstable at low temperature (below zero degree centigrade), because the metal tends to be brittle and susceptible to crack. In this research studying some physical properties such as shrinkage, adhesion force and coating layer thickness of aluminum powder with ethyl silicate as a binder were performed. The results shown, that the coating with such layer has excellent resistance to low temperature and impermeable to liquid gas for example, propane, methane and nitrogen a suitable coating layer thickness is (5mm). The data and results were optimized by using Taguchi / ANOVA Technique.

دراسة تأثير درجة الحرارة المنخفضة متانة الالتصاق لطبقة التبطين الداخلي لحاويات خزن الغاز السائل
المصنوعة من الفولاذ

الخلاصة

حاويات خزن الغاز السائل المعدنية تكون غير مستقرة بدرجات الحرارة المنخفضة (تحت الصفر المئوي)، لأن المعدن يميل الى ان يصبح هش ويكون معرض للكسر. في هذا البحث تمت دراسة الخواص الفيزيائية مثل الانكماش، قوة الالتصاق، وسمك طبقة الطلاء المكونة من مسحوق الالمنيوم وأثيلات السيليكا كمادة رابطة. أظهرت النتائج بأن طبقة الطلاء امتازت بمقاومة ممتازة في درجات الحرارة المنخفضة وأنها غير مسامية للغازات السائلة مثل البروبان، الميثان والنيتروجين. ان أفضل سمك لطبقة الطلاء (5 ملم). أجريت عملية الامثلية الرياضية للبيانات والنتائج باستخدام تقنية تاكوجي/ أنوفا.

Introduction

Paints and coatings of all types are widely used to provide color and pleasing aesthetics, and to prevent deterioration of the underlying substrate when exposed to various environments. Besides protection and beauty, however, coatings provide light reflectivity, camouflage surfaces, reflect and absorb heat, and provide a variety of other functions [1].

However, in order to provide these functions, the protective coating must remain intact and adherent on the surface to which it has been applied. The vast majority of all protective coatings perform admirably until an old age, at which time natural deterioration and degradation occur. However, a coating can fail prematurely, preventing its aforementioned functions from being realized [2].

The major reasons for the occurrence of corrosion usually are poor or deficient surface preparation, or insufficient coating thickness. There are, of course, many other reasons why coatings deteriorate and corrosion occurs [3, 4]:

- A paint or coating is incorrectly formulated or manufactured by the coating supplier.
- An unsuitable coating is specified for a given environment.
- Environmental conditions are different than that understood by the specifier.
- There is improper, or insufficient, mixing of the coating at the time of application.
- There are adverse ambient conditions when the coating system is applied.
- The drying and/or curing of the coating after application is impaired.
- There is chemical, physical, and/or mechanical damage to the coating system during exposure.

These causes of failure are relevant only when a premature coating failure occurs. Instead, most protective coatings are successfully specified and applied to a properly prepared surface to the appropriate thickness [5].

These coatings perform as intended, but over time deteriorate and lose their protective or aesthetic function as a result of old age, combined with exposure to aggressive environments. There are a variety of environmental stresses that combine to degrade coatings exposed in a service environment [6, 7].

The aim of this paper suggests Aluminum powder mixed with ethyl silicate as a binder to make using layer on inside surface area of a liquid gas steel container.

Therefore the multi-layered container with the Al powder and ethyl silicate intermediate wall is introduced which promises both the thickness reduction of the tank outer wall and higher coating storage tanks.

The coating is responsible for supplying a certain amount of strength and good adhesion to the tank. When the container is filled with liquid gas, it decreases the temperature.

The main property of this compound is to decrease the porosity and create an additional support to the outer wall in encountering the low temperature inside.

In this sense it can also be stated that the tank adjusts its own strength and lower factor of safeties than the standards may be applied as well. Furthermore, this wall is going to reduce the total tank weight since it will be made of lightweight materials. At last but not at least, the out wall is expected to reduce the permeation rate of liquid gas through the walls to the outside, so the leakages can be significantly reduced.

Experimental Procedures

Samples of (low carbon steel) were used with dimension (10*40*1) mm. Coating process was performed after samples primary and secondary preparation, by using pressure spraying system [8].

Coating layer includes (50 micron) aluminum powder mixed with ethyl silicate as a binder shown in tables (1 and 2) respectively.

Table (1) The composition of Commercial Purity aluminum (AA 1060).

Al	Si	Fe	Ti	V	Cu	Mn
99.76	0.08	0.15	0.001	0.007	0.001	0.003

Table (2) The composition of ethyl silicate

SiO ₂	ETHYL ALCOHOL	water
41%	12%	Rem.

Form of ethyl silicate having an SiO₂ content of above 50% comprising reacting partially condensed ethyl silicate having an SiO₂ content of about 40% with an aqueous ethyl alcohol containing less than 11% byweight of water based upon, said water being sufficient to partially condense said ethyl silicate to an SiO₂ content of above 50%.

Three factors and their effects on the adhesion force were studied. The factors and their levels are illustrated in table (3).

Table (3) Factors and their levels

Factor	Level 1	Level 2	Level 3
Al %	15	30	45
Coating Thickness mm	1	3	5
Temperature C ^o	-5	-10	-15

Each sample after coating has been bend by using U- bending tool, The purpose of bending process is to expose the outside surface of the sample (i.e coating layer) to tension as shown in figure (1). Each sample after bending were locating in cooling chamber at required temperature. Taguchi orthogonal array method was used to determine design of experiment [9]. Nine experiments were run as shown in table (4).



Fig. (1) Coated samples after bending operation.

Table (4) Design of Experiments via Technique

	C1	C2	C3	C4	C5	C6	C7	C8
	Al%	Coating Thic. (mm)	Temp. (C)	Trial 1	Trail 2	Trail 3	Mean	S/N ratio
1	15	1	-5	4.1	4.3	4.1	4.16669	6.19800
2	15	3	-10	4.2	4.6	4.3	4.36667	6.40155
3	15	5	-15	5.2	5.1	5.3	5.20000	7.16000
4	30	1	-10	4.2	4.5	4.1	4.26667	6.30090
5	30	3	-15	5.7	5.6	5.3	5.53333	7.53003
6	30	5	-5	5.6	5.2	5.9	5.56667	7.45600
7	45	1	-15	5.9	6.2	6.0	6.03333	7.80556
8	45	3	-5	7.5	7.8	7.4	7.56667	8.79007
9	45	5	-15	8.0	8.0	9.0	8.33333	9.20818

Where trial 1, 2, and 3 represent adhesion strength in KN.

Response table for S/N ratio

Table (2) was used to obtain response table for S/N ratio (Larger is better) in order to determine which factor has strongly significant effect on the adhesion force of the coating layer, the data of such table illustrated in table (5).

Table (5) Response Table for S/N Ratio

Level	Al%	Coating thickness(mm)	Temperature(C)
1	13.17	13.54	14.93
2	14.12	15.08	14.61
3	17.20	15.88	14.96
Delta	4.03	2.35	0.35
Rank	1	2	3

From table 3 it has been shown that the percentage addition of aluminum powder has a high delta value (4.03) with rank1. Coating thickness has secondly significant effect on the adhesion force with rank 2 and (2.35) delta value. Finally temperature has weakly significant effect on the adhesion force.

Main effect plot of S/N ratio

Data carried out in table 3 are used to plot main effect plot for signal to noise ratio[10], from which it has been shown that the high adhesion force was achieved at level 3 for all factors as shown in fig. (2)

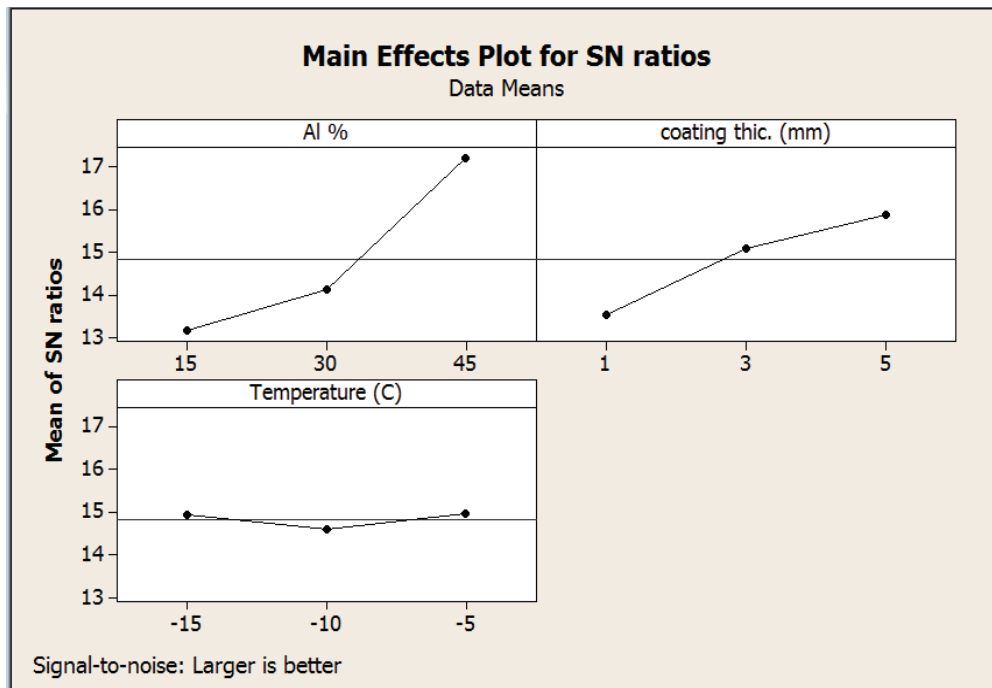


Fig. (2) Main effect plot for signal to noise ratio

Analysis of variance ANOVA:

General regression analysis was used to evaluate the effect of two factors on the adhesion force, as shown in table 6.

Table (6) Analysis of Variance

Source	DF	Seq. ss	F	P
Regression	4	15.700	11.950	0.0170
Al%	1	11.210	4.001	0.116
Al%*coating thickness.	1	3.962	0.406	0.560
Al%*temperature	1	0.0108	0.743	0.440
Coating thickness*temperature	1	0.508	1.550	0.301

Predictive Model Generation

Predictive model was built by using Minitab 16 / general regression analysis as the experiments are considered multiple control factors (three control factors). General regression is part of statistical that deals with the investigation of the relationship between the control factors and their interactions and the required response [11,12]. The regression model can be expressed by the following equation:

$$\text{Mean} = 2.01966 + 0.106105 \text{ Al \%} + 0.00480507 \text{ Al \%} * \text{coating thic. (mm)} + \\ 0.0021764 \text{ Al \%} * \text{Temperature (C)} - 0.0229344 \text{ coating thic. (mm)} \\ * \text{Temperature (C)}$$

Confirmation experiments:

The above experimental analysis, main effect plot for S/N ratios show that the maximum adhesion force can be obtain with the following conditions presented in table 7

Table (7) Optimal design conditions

Factor	Best level
Al%	45
Coating thickness(mm)	5
Temperature	-15

Three experiments were performed under the optimal conditions in order to validate the optimization, from which it has been shown that the results of confirmation experiments and the predicted by optimization procedure are considered to be valid based upon the results of Taguchi experiments and within the 92.28% confidence interval.

Conclusion

Coating of low carbon steel by layer consists of (50 micron) aluminum powder mixed with ethyl silicate as a binder was performed in this study. The coating layer showed excellent resistance against the bending operation as well as at temperature below zero Celsius degree centigrade. Percentage aluminum added and thickness of coating layer, play an important role in the adhesion of coating layer on the substrate surface. Taguchi/ ANOVA optimization assists to obtain high adhesion force of the substrate coating, and confirmation experiments revealed that the optimal adhesion force obtained under optimal factors conditions. the results of confirmation

experiments and the predicted by optimization procedure are considered to be valid based upon the results of Taguchi experiments and within the 92.28% confidence interval. The results obtained from the study indicate that the coating layer is suitable for the lining of the steel containers.

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