EFFECT OF STEEL CASING SURFACE CONDITIONS ON THE ADHERENCE OF OILWELL CEMENTS

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Abstract. *The adherence between cement sheath and steel casing is essential to assure both mechanical stability and zonal isolation of oilwells. Serious economic and environmental issues are often related to interfacial cracking, especially in wells submitted to steam injection to stimulate oil recovery. The topography of the surface of the metallic casing as well as the composition of the cement slurry significantly affect the adherence of this interface. In the present study, a test probe was designed to evaluate the strength of cement-casing interfaces using conventional uniaxial strength measurements. Plain carbon steel samples were sanded (transversally or longitudinally) or sandblasted in order to study the effect of the topography on the adherence of the cement. The results revealed that the mechanical strength of the cement-casing interface can be improved by as much as 190% by removing oil coatings and increasing the roughness of the casing.*

Keywords: *oilwell casing, cementing, cement-metal interface*

1. Introduction

The cement sheath is responsible for the mechanical integrity of oil wells. In addition, sound cemented sheaths also provide zonal isolation, preventing contact between producing areas as well as with adjacent rock formations, thus selecting the access of oil, gas or water according to the production schedule of the well. Several adversities linked to faulty cementing may take place during the producing period of an oilwell (Nelson, 1990). Although squeeze operations are routinely employed to correct cement flaws, they not only involve reasonably high costs but also interruption of the production of a well. Cracking of the cement is intimately related to weak cement-casing interfaces, especially in wells submitted to steam injection to stimulate oil production.

The estimated oil reserves in Northeastern Brazil account for approximately 1.5 billion barrels, most of which characterized by high viscosity, and consequently, low recovery factors. The production of viscous oils is commonly stimulated by the injection of steam. However, the high temperatures involved in this procedure not only lower the viscosity of the oil assisting its recovery but also submit the cement-casing interface to thermal cycles. As a consequence of the thermal expansion mismatch between cement and steel and the brittle nature of the former, extensive interface cracking can be expected resulting in severe damage to the cement sheath. Fluids flow through the annular region of the well, which loses zonal isolation. Contamination of the produced oil and negative economical, environmental and safety impacts are the most common outcomes in this scenario. In addition, the topography of the surface of the metallic casing also affects the adherence of the interface (Bearden, 1961). The completion of an oilwell is often made using machined oil-coated casings, which negatively affects both interface adherence and mechanical interlocking of the hardened cement slurry.

In order to adequate the well sheath to steam injection, cement slurries capable of developing plastic behavior under stress as well as adherent casing-cement interfaces are required. Improving the mechanical coupling between cement and metallic casing can be easily achieved in field operations and may be the only possible solution since chemical adherence between cement and casing is hardly expected to occur. Therefore a combination of better cement properties and improved mechanical interlocking may potentially reduce the number of wells that demand squeeze operations. Estimates from oil companies indicate that the direct cost of a squeeze operation is around ~ US$ 30,000.00 and the number of oilwells in Northeastern Brazil depicting such problem has significantly increased in the last few years.

In this scenario, the importance of previously evaluating the adherence of cements to well casings becomes evident. Although testing methodologies are available to assess the adherence of cement-metal structural systems, they are not usually applied to the geometry and well conditions encountered in cement sheath-casing couples. Therefore, the study reported herein focused on designing a test probe suitable for evaluating the strength of cement-casing interfaces using conventional uniaxial strength measurements. After that, different casing surface topography and roughness, i.e., transversal and longitudinal sanding, and sandblasting were tested in order to assess the effect of the surface condition on the adherence of the cement. Finally, the cleanliness of the surface was also evaluated by applying an oil coating onto casing samples and evaluating the strength of the interface with cement.

2. Experimental Procedure

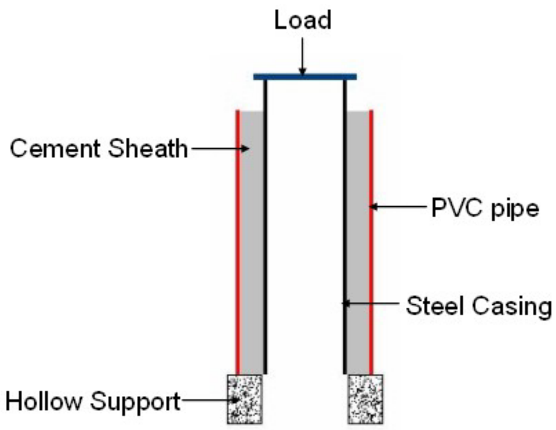
2.1. Slurry preparation

A constant speed mixer was used to prepare 600 ml batches of cement slurry whose water to cement ratio was 0.44, as conventionally used for oilwell cements. No additives were used. The constituents were mixed for 15 s at 4000 rpm and, subsequently, for 35 s at 12000 rpm, according to NBR 9826 (ABNT, 1993(b)) standards. This procedure emulates the mixing energy provided by field equipments to larger cement batches (PAIVA, 2003).

2.2. Adherence tests

The test method employed aimed at simulating a cemented well sheath section. It consisted of a metallic casing (carbon steel) surrounded by a hardened cement sheath constrained by a PVC pipe, as schematically shown in Figure 1a. The outer diameter of the steel casing was 42.35 mm and the internal diameter of the PVC pipe was 75.00 mm. The ratio between these values is consistent to actual dimensions used in the field. The length of the steel casing and PVC pipe were 170.00 and 150.00 mm, respectively, in order to minimize border effects, typical of lab tests but not actually observed in real cemented well sections. The difference in height allowed the compression of the steel casing against a hollow base which supported the cement sheath.

Therefore, the shear strength necessary to detach the sheath from the metallic was measured. This value represents the resulting action of the stresses generated along the entire perimeter of the metal-cement interface, simulating the mechanical conditions to which cemented well sections are submitted and is directly related to the adherence of the interface. The numbers presented in this study represent the average strength of four tests for each surface condition evaluated. After the rupture of the interface, the test was halted. The PVC pipe was sawed out and the test resumed to completely remove the steel casing. The outer surface of the casing and the inner surface of the sheath were evaluated by digital images in an attempt to detect the presence or not of cement attached to the casing. Four different steel casing surface topographies and roughness were tested, as discussed below. An actual test assembly can be seen in Figure 1b. A Shimadzu AG-I 100KN machine was used for the mechanical tests carried out after hardening of the cement slurries for 24 h.



(a) **(b)**

Figure 1. (a) Schematics of cement-steel casing assembly and (b) Image of sample positioned for test.

2.3. Casing Surface Treatment

The steel casing samples used to assemble the mechanical test probes depicted an oxide superficial layer typical of manufacturing and storing conditions (Figure 2c). In order to prevent further oxidation, casing sections are commonly coated with oil. These are the most common surface conditions encountered in real oilwells. In this study, casing samples depicting both surface conditions were cemented and tested. In addition, alternative surface conditions were also investigated. In order to improve mechanical interlocking and adherence to the cement sheath, the surface of the steel was cleaned with a solvent, and treated to increase roughness. Samples were transversally or longitudinally sanded (Figure 2a) using 60 mesh SiC paper. Sandblasting was also tested (Figure 2b) to assess its effect on the adherence of the cement. The cleanliness of the surface was evaluated by applying an oil coating onto as-received casing samples.

(a)

(b)

(c)

32 mm

Figure 2. Steel casing surface conditions tested. (a) Sanded, (b)sandblasted and (c) as-received. Oily surface not shown.

2.4. Roughness tests

The roughness of the steel casing surfaces was measured using a Taylor-Hobbson Surtronic 3 system. The parameter used to represent roughness was Ra, and the cut off used was 0.8 mm.

3. Results and Discussion

The results of the mechanical strength tests carried out for all four casing surface conditions are shown in Figure 3. The geometry of the sample used in the test was adequate to generate a mechanical parameter which assesses differences in the strength of the assembly. The numerical values of the test can, therefore, be associated to the adherence of the cement-casing interface and be used in lab evaluation of both slurry and casing properties.

As it could be expected, the strength of the interface increased by degreasing the surface with an oil solvent. The average force measured from the tests increased from 0.2 to 6.41 kN (as-received condition). Increasing the roughness of the surface further increased the strength of the interface. By transversally sanding the casing with SiC paper 60 mesh, the average force measured during the test increased from 6.41 kN to 14.3 kN, which corresponded to an improvement of 120% with respect to the as-received condition. Longitudinally sanded samples revealed an increase in strength of ~40%. However, the best results were achieved upon for sandblasting. The average force measured during the tests was 18.54 kN, which corresponded to an increase of ~190% with respect to the as-received condition. As the composition of the cement was the same for all tests, it can be safely inferred that the improvement in interface strength was solely related to better mechanical interlocking of the cement with the surface of the metallic casing. This can be further corroborated comparing the results obtained from sanding the surface in different directions. The scratch pattern created perpendicularly to the direction of the applied force was more effective in holding the cement sheath against the metallic casing compared to the scratch pattern created in the direction of the applied load. The actual surface condition, i.e., that corresponding to the casing coated with an oil layer, resulted in the lowest values. This explains why the number of oilwells requiring cement squeeze operations has considerably increased, especially those submitted to steam injection. The presence of an oil coating prevents both physical contact and mechanical interlocking between cement sheath and metallic casing, which drastically limit the adherence of the cement-casing interface. As it can be seen from Figure 4, there is a linear relationship between the strength of the interface and the roughness of the metallic casing surface.

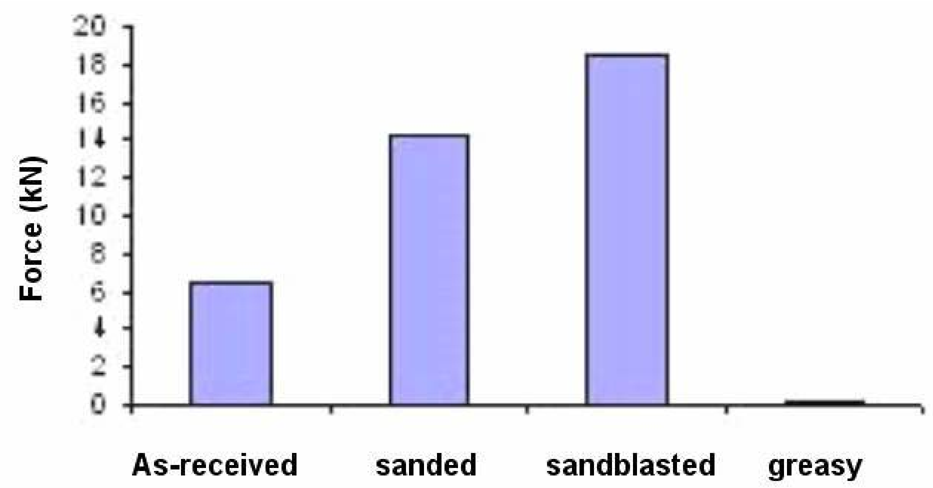


Figure 3. Mechanical test results for cement-casing samples as a function of casing surface condition.

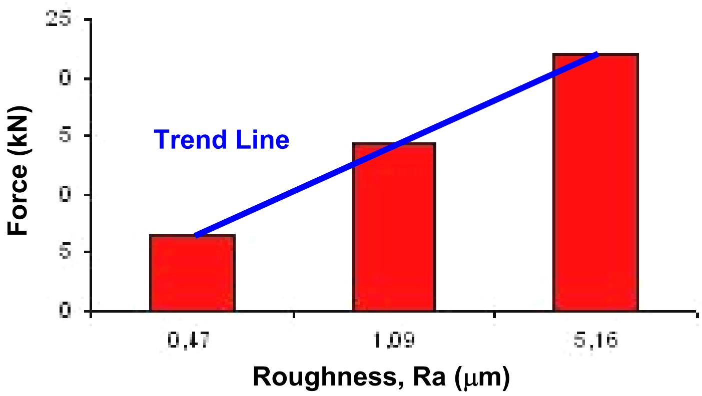


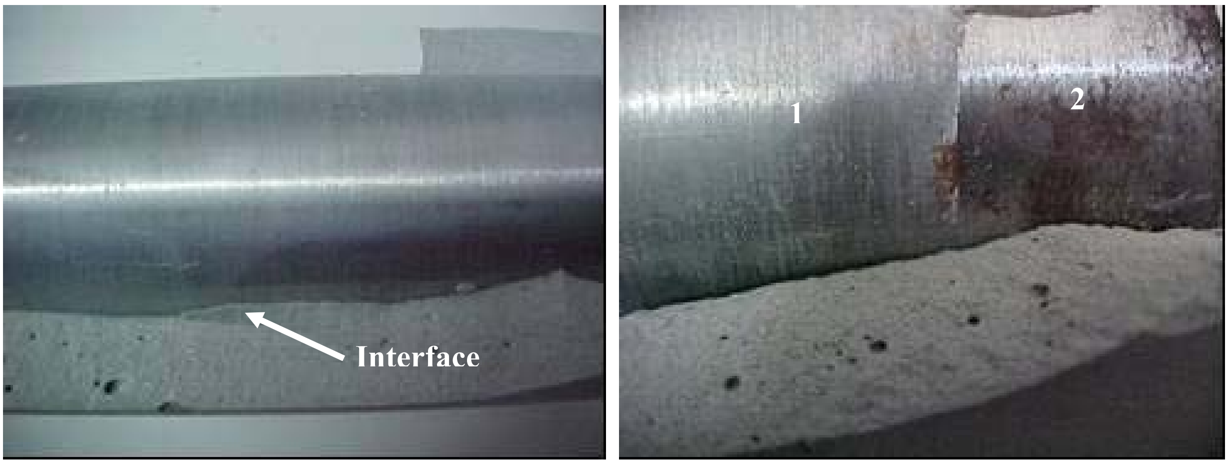
Figure 4. Test results for cement-casing samples as a function of roughness of the casing surface.

The interaction between cement and metallic casing can be seen from the images shown in Figures 5 to 8. They correspond to digital pictures taken after the PVC pipe was sawed off and the assembly tested up to full removal of the cement sheath. The casing cemented in the as-received condition (Figure 5) revealed virtually no interaction of the cement with the metallic surface, as it can be seen from area (1) marked in Figure 5a. On the other hand, part of the oxide layer and oil residues originally present on the surface of the casing adhered to the cement sheath, as it can be clearly seen in area 2, Figure 5b, thus lowering the mechanical strength of the interface, as registered from the shear tests previously discussed.

(a) **(b)**

Figure 5. Tested sample. Casing in the as-received condition. (a) Casing, (b) Cement Sheath.

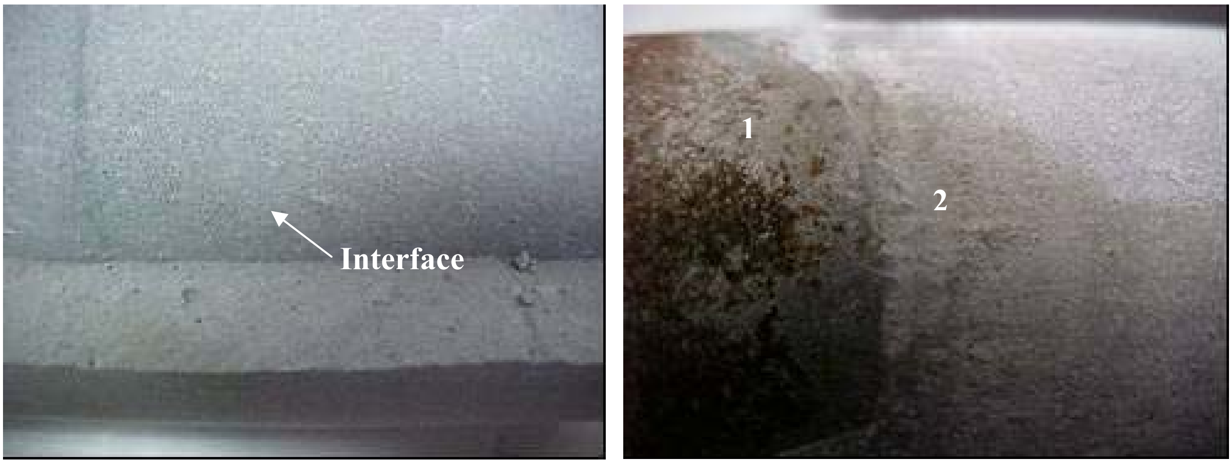
The aspect of the surfaces of the cement and casing corresponding to a tested transversally sanded casing sample is shown in Figure 6. The presence of cement is visible, especially comparing the brightness of areas (1) and (2), pointed out in Figure 6b. Area (1) has a thin and discontinuous cement layer coating it, whereas area (2) is characterized by the scratch pattern and oxides developed after the test. These images illustrate the importance of the surface roughness and direction of the scratch pattern in interlocking the cement sheath with the metallic casing, ultimately improving the strength of the interface.



(a) **(b)**

Figure 6. Tested sample. (a) Transversally sanded casing and (b) Corresponding Cement Sheath.

The casing surface of a tested sandblasted sample is shown in Figure 7. The adherence of the cement to the casing is clearly noticed by the significant amount of cement that remained attached to the sandblasted surface of the casing after the test (Figure 7a). Moreover, a contrast can be noticed comparing areas (1) and (2) in Figure 7b. The region highlighted is near the top of the sample. Area (1) was not cemented and reveals only the features of the sandblasted surface oxidized after the test, whereas area (2) .corresponds to a cemented region. Once again, the presence of cement adhered to the metallic casing is evident.



(a) **(b)**

Figure 7. Surface of sandblasted steel casing after mechanical test. (a) Cemented area. (b) Close to the top.

Finally, the surface of a tested sample coated with an oil layer is shown in Figure 8. No adherence of the cement to the casing could be observed, explaining the considerably low strength values registered in the mechanical tests. The surface of the cement (Figure 8a) was impregnated with oil. No cement could be observed on the surface of the tested casing (Figure 8b), thus explaining the virtually null values of mechanical strength measured from this kind of interface.

Therefore, casing surface cleaning and increased roughness can significantly enhance the adherence of the cement sheath to the metallic casing, improving the mechanical soundness of oilwell cement sheaths. Oil companies can benefit from sandblasting their steel casing and using oil solvent prior to lowering their casing to the well. Sandblasting is a feasible and cost-efficient field procedure, especially taking it account not only the economical aspect of preventing squeeze operations but also the safety and environmental outcome of cementing sound oilwell sheaths.

(a) **(b)**

Figure 8. Surface of tested sample coated with an oil layer (a) Entire length and (b) detailed image..

4. Conclusions

A new and simple test probe was designed to assist the evaluation of the adherence of cement-steel interfaces especially designed to simulate oilwell sheath-casing systems. The geometry and dimensions of the samples resulted in a range of mechanical strength values capable of distinguishing differences in applied loads corresponding to differences in casing cleanliness and roughness. Metallic casing samples were sanded (transversally or longitudinally) with 60 mesh SiC paper or sandblasted in order to assess the effect of the topography on the adherence of the cement. The results revealed that the mechanical strength of the cement-casing interface can be improved by as much as 190% by removing oil coatings and increasing the roughness of the casing. Sandblasting is an efficient method to improve the adherence of cement-steel casing interfaces, potentially reducing the necessity for squeeze operations, generally required after steam injection.

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