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# METHODOLOGY FOR ASSESSING DESTRUCTIVE TOOLS OF COLUMN PARTS USED IN OIL WELLS

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***Abstract.*** *During the drilling of oil wells, parts from the column, head or even the drill could get stuck inside the well and stop the operation. Then, in order to restore the drilling, initially an operation so-called fishing is carried out in order to "fish" the stuck part out of the well. If the fishing operation does not remove the part, it is necessary to proceed to the destructive operation, which aims to clean up the well. This operation requires special tools, so-called destructive tools. Due to the high costs involved in oil exploration, it is essential that these tools fulfill their functions, i.e., they must not fail and clean up the oil well. Therefore, it is important to assure the quality of manufacturing the destructive tools, which is normally carried out by brazing a rod made of tungsten carbide in alpaca matrix (Cu-Zn-Ni alloy) over alloyed steel body. Therefore, this work aims to propose a methodology for accreditation of destructive tools of column parts used in oil wells, through the assessment of consumables, manufacturing process (brazing) and the final tool (simulative test). Computational routines were developed, as well as gravimetric, impact and simulative tests. The results showed that image processing and analyses are effective in the consumable assessment. Gravimetry showed capable of distinguish mass percentage of tungsten carbide and alpaca in the rod (consumable). The modified Izod impact test is a suitable approach for analyzing the fracture of the brazed deposit. The simulative test indicates carbide granulometry and tool rotation that is more appropriated for using during the destructive operation of oil wells.*

***Keywords:*** *Brazing, exploration, oil wells, Destruction, Crushed carbide*

## 1. INTRODUCTION

During drilling of oil wells, a column part of the perforation drill could become stuck inside the well, because its fracture or deformation. In any case, the free part of the column must be pull back and a clearing operation of the oil well is demanded. The first approach is the attempt to pull back the stuck part during an operation so-called "fishing", with appropriated hydraulic tools. However, sometimes the stuck part cannot be "fished". Then, a second approach takes place and the stuck part is destructed ("machined") until a certain point (normally governed by torque monitoring), when the fishing operation is again tried for the remaining part (Parveen, 2010). Figure 1 illustrates this operational procedure.

Since the "fish" (stuck part) is normally a metallic material and the obstruction takes place during the drilling, the destructive operation is mainly carried out during the by using another column with proper preparation. The destructive tools can be hollow or not with hardfacing material deposited at it ends by oxyfuel brazing, as shown in Fig. 2. The hardfacing material is normally made of a matrix of Cu-Zn-Ni alloy (known as alpaca) and crushed tungsten carbides (WC) with less than 7%-Cobalt addition (although some companies have adapted hard metal from machining process that have ~14% Co, which leads to lower hardness, but higher toughness) (Vilarinho et al., 2005).

These destructive tools are manually manufactured and because of not-so-evident aspects good homogeneity is not achieve for tool performance. This leads to low operation times for the destructive tools, low perforation speeds and even a new column break, which can definitely close the well. Since the rent of an offshore drilling platform costs around US$ 500,000.00 a day (Sermão, 2009) in the case of Brazil's shore and the destructive operation takes between one and three days, the guarantee of homogeneous operation with complete clearance of the well is fundamental.

Operational problems during the manufacturing of destructive tools are associated to the difficulty of defining and qualifying an operational procedure for consumables acceptance (rod of WC+alpaca), i.e., their certification, an operational procedure for brazing process and an operational procedure to simulate different conditions of consumables and deposition/personnel to assess their influence over the destructive operation. Specific standards for this situation are not available and oil companies depend on key personnel to carry out this operation. In case of Brazil, there are less than a dozen of capable personnel to carry out destructive operation, which is a challenger for the recently discover pre-salt fields (Vilarinho et al., 2005), where the majority of oil wells are offshore.

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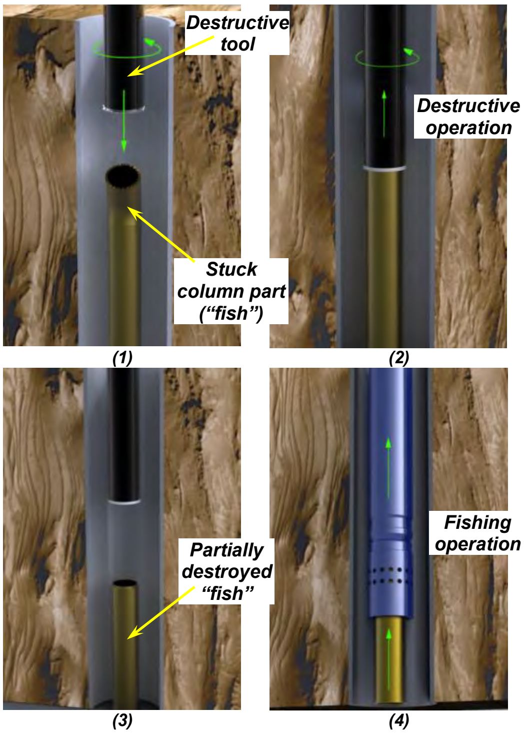


Figure 1. Schematic sequence of fishing and destructive operation in oil well (after Hughes, 2002)

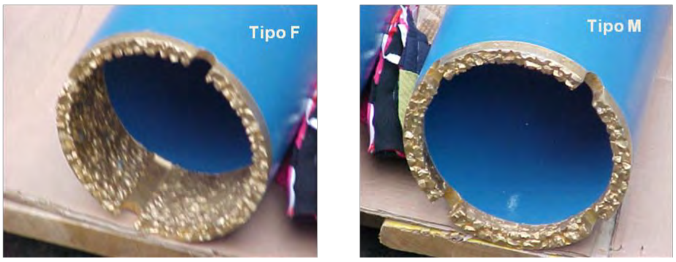


Figure 2. Examples of destructive tools

Therefore, this work aims to propose and assess different technical and practical methodologies to establish operational procedures for consumables acceptance, for production of brazed deposits and for simulative test, in order to assure homogeneity and quality of destructive tools used in oil wells.

Three approaches were developed and are schematically shown in Fig. 3. These approaches are the proposition of standard procedure for consumable acceptance; the proposition of standard procedure for production assessment and the proposition of standard procedure for simulative test under laboratorial conditions.

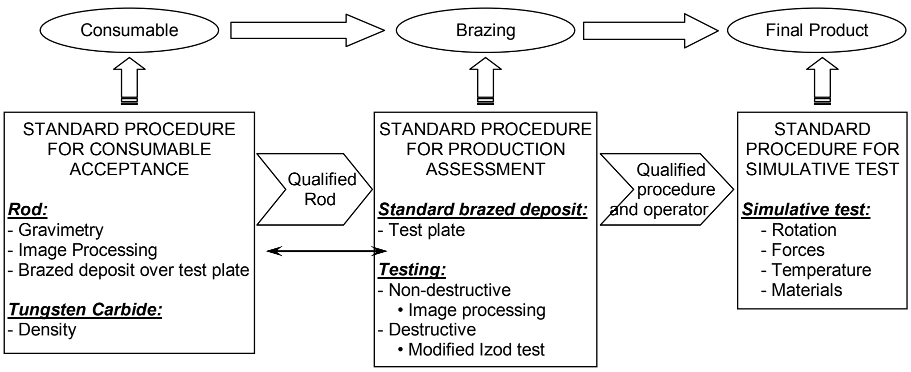


Figure 3. Operational procedures developed in this work to cover the manufacturing of destructive tools

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## 2. STANDARD PROCEDURE FOR CONSUMABLE ACCEPTANCE

Rods of crushed tungsten carbide with Cobalt addition (WC-Co) are used are primary consumable to be brazed over the column part that will become the destructive tool. This rod is shown in Fig. 4. The homogeneity in this rod is important, since the carbides are in a “crushed” form, with larger dimension normally up to ½”. If the disposition of carbides in the rod is not uniform, the welder will not be able to correctly re-arrange the carbides at the surface of the tool. Each carbide “stone” must be carefully distributed over the tool to assure that during its rotation, carbides are constantly in contact with the stuck part to be destroyed. If not, alpaca matrix (Cu-Zn-Ni alloy) is very soft and its function is to sustain the carbides and absorb impacts and not to destruct. This is a major concern when buying the rods, i.e., the carbides distribution must be uniform and with determined proportion in respect to alpaca, otherwise alpaca does not destruct and is cheaper than carbides. Mass percentages between 44% and 53% of WC-Co are acceptable (Vilarinho et al., 2005).

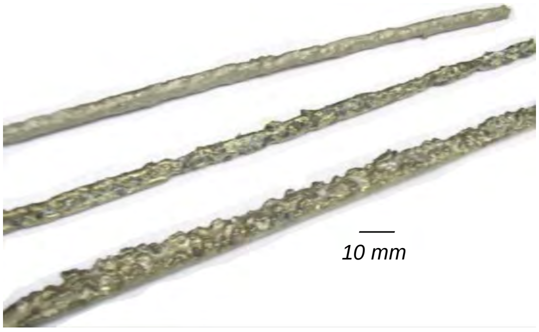


Figure 4. Samples of WC-Co rods

Two methods are proposed to assess both features of percentage and distribution of carbides. The first one is gravimetry to determine carbide percentage, i.e., the rod is weighted in air and in water and the percentage of carbides and alpaca calculated by their density. This is a simple and practical test to be carried out at shop facilities. The uniformity of carbide distribution on the rod was assessed by image processing as seen in Fig 5. Pictures of the rod are taken in six different angular positions (0°, 15°, 30°, 45°, 60° and 75°) with backlight, so only the shadow of the rod is identified. This shadow is image processed and the profiles of the two edges of the rod are analyzed in respect to their standard deviation and integral under their FFT (Fast Fourier Transform). Again, this must be a simple operation to be carried out in shop floor. The photographic set for rod rotation is just a light bulb under white paper cover with the rod manually turned. The image processing is automatic and only demands the image chosen. At the end, only two results appear: good for variation of standard deviations up to 60% and FFT integral less than 50 pixels and or bad, in all other cases (Vilarinho et al., 2005).

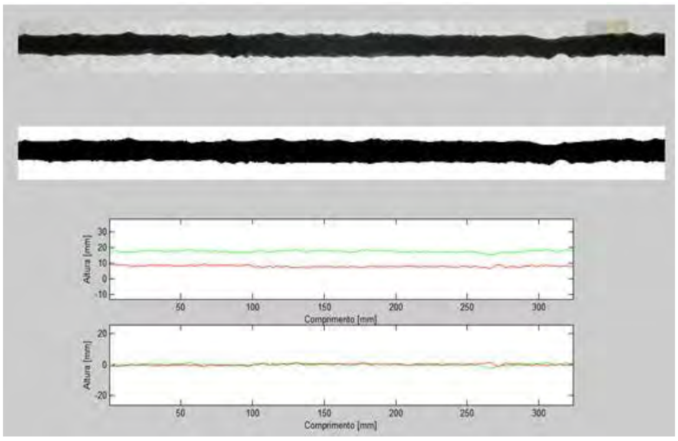


Figure 5. Example of image processing in a WC-Co rod showing the edges profiles after image processing

As an example of consumable acceptance, Tab. 1 brings carbide granulometry that will be used to demonstrate the standard procedures proposed in this work. Alpaca and WC-Co densities were measured as shown in Tab. 2 and the measures during gravimetry with final results are shown in Tab. 3. Since WC-Co percentages between 44% and 53% of are acceptable (Vilarinho et al., 2005), samples Fine2 and Fine 3 are discarded.

The results for image processing are shown in Tab. 4. They evaluated the distribution of carbides in the rod, which is fundamental for welder uniformly deposits it. Criteria are based in the variation of standard deviation of edge profile of the rod and the integral from FFT curve during image processing. In this case, only rods Fine1 and Fine2 are uniform rods concern WC-Co distribution. As gravimetric test discarded rod Fine2, only rod Fine1 is acceptable.

Table 1. Employed WC-Co granulometry

| Granulometry | Size (mm) |
|---|---|
| Fine | 2 to 4 |
| Coarse | 6 to 8 |

Table 2. Density measurement for alpaca and WC-Co

| Samples | Mass (g) | Volume (ml) | Density (g/cm$^3$) |
|---|---|---|---|
| Alpaca 01 | 5.715 | 0.7 | 8.1 |
| Alpaca 02 | 1.814 | 0.2 | 9.1 |
| WC-Co 01 | 4.302 | 0.3 | 14.3 |
| WC-Co 02 | 11.972 | 0.8 | 14.9 |

Table 3. Gravimetry results for consumable acceptance

| | Fine | | | Coarse | | |
|---|---|---|---|---|---|---|
| Sample | 1 | 2 | 3 | 1 | 2 | 3 |
| Massa in air (g) | 277.36 | 254.56 | 296.57 | 482.66 | 424.65 | 446.15 |
| Massa in water (g) | 252.73 | 227.76 | 265.42 | 438.41 | 387.79 | 405.31 |
| Volume (cm$^3$) | 25.11 | 27.32 | 31.75 | 45.11 | 37.57 | 41.63 |
| Density (kg/m$^3$) | 11.05 | 9.32 | 9.34 | 10.70 | 11.30 | 10.72 |
| WC-Co volume (%) | 41.84 | 10.35 | 10.74 | 35.53 | 46.48 | 35.82 |
| WC-Co mass (g) | 149.59 | 40.25 | 48.58 | 228.19 | 248.69 | 212.38 |
| WC-Co percent (%) | 53.93 | 15.81 | 16.38 | 47.28 | 58.56 | 47.60 |

Table 4. Image processing results for consumable acceptance

| Samples | Variation of standard deviations (less than 60%) | FFT integral (less than 50 pixels) | Conclusion |
|---|---|---|---|
| Fine1 | 15.7 | 37.9 | Good |
| Fine2 | 8.0 | 34.9 | Good |
| Fine3 | 95.1 | 76.0 | Bad |
| Coarse1 | 51.5 | 120.7 | Bad |
| Coarse2 | 30.8 | 86.5 | Bad |
| Coarse3 | 126.0 | 66.4 | Bad |

This result shows how difficult is to find good consumables, i.e., only one out of six rods can fulfill the requirements of homogeneity for consumables (rods). Therefore, this standard procedure for consumable acceptance is fundamental to assure quality of destructive tools. It also must be pointed out that there are other consumables, such as the gas used for oxyfuel brazing, fluxes and the column material itself. These materials have good standards (for instance, AWS, ASM, ASTM, etc) to asses them and their must be also be taking into account.

## 3. STANDARD PROCEDURE FOR PRODUCTION ASSESSMENT

Once the WC-Co+alpaca rods have been qualified by using the standard procedure for consumable acceptance, the next step is to qualify the brazing procedure and the welder. Of course, there are different standards for procedure and performance qualification (AWS, ASME, API, etc). However, they do not cover the specificity of this application, which requires both uniform distribution of carbides and physical adherence of the deposit carried out by brazing.

Therefore, two tests were proposed basing on the analyses of the brazed deposit over a test plates: one non-destructive and other destructive. The first one is based on image processing of brazed deposit over a 250 x 150 x 25.4 mm plate (Fig. 6). The algorithm identifies areas without the presence of carbides depending on the granulometry. If at least one area greater than carbide granulometry is found, the production of the deposit is considered failed.

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Figure 6. Brazed deposit over test plate (250 x 150 x 25.4 mm) for fine (left) and coarse (right) granulometries

The destructive test for assessing the adherence of the deposit is carried out by using a modified version of Izod test, which measures toughness, similarly to Charpy test. Modification in a Charpy machine was carried out to proper clamp a sample of 25 x 10 x 25 mm and with at least 20 mm of brazed deposit as shown in Fig. 7. The clamping system holds the steel part of the sample and the impact hammer hits the brazed deposit. This sample comes from a plate with 250 x 25 x 25 mm, brazed a minimum of 20-mm-thickness deposit. The sample is taken by Electrical Discharge Machining, due to the high hardness of tungsten carbides. Each sample takes approximately 8 hours to be machined in both sides.

One example of analyses with fine and coarse granulometries previously discusses is shown in Fig. 8. In this test, none of the plate was discarded, i.e., they presented uniform distribution of crushed carbides over the test plate.

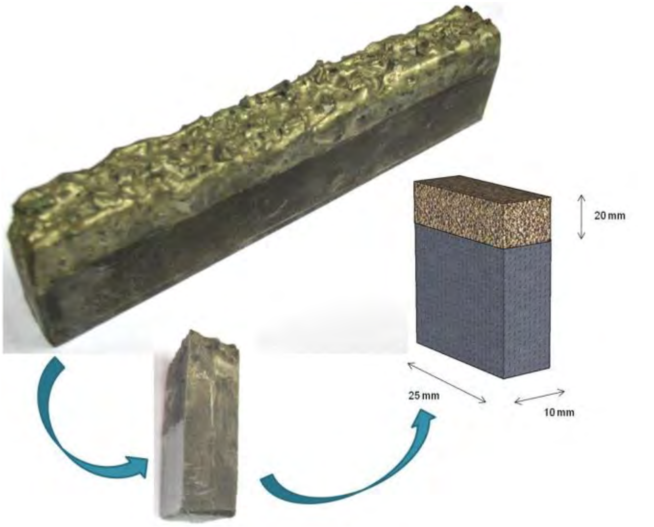


Figure 7. Test plate and sample for modified Izod test

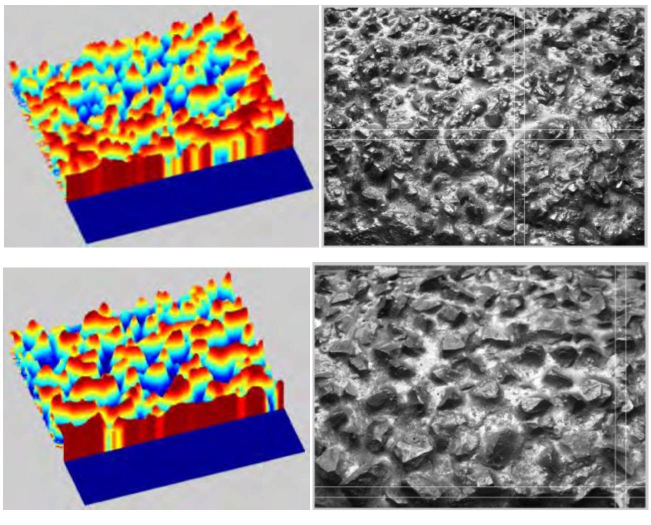

Figure 8. Example of image processing of brazed deposit for fine (top) and coarse (bottom) granulometries

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For modified Izod test both absorbed energy and fracture location are analyzed. From granulometries discussed, six deposits were carried out and results for energy are shown in Tab. 5. From this table, it is possible to observe that Coarse1 and Fine1 samples has the higher absorbed energy, which in the case of Fine1 sample represents a good performance from consumable acceptance criteria.

Fracture locations of samples are shown in Fig. 9. Fractures that happen in the brazed interface (bonding zone) are considered inappropriate, since it could represent a failure during brazing process. Thus, fracture in the deposit zone is considered suitable. Fig. 9 illustrates both locations of fracture observed during the experiments and Tab. 6 presents the results for the fracture locations for each tested sample. Results in Tab. 6 indicate that Coarse3 sample presented all trials with fracture in the bonding zone. This validates the results from Tab. 5, since Coarse3 sample has the highest absorbed energy. On the other hand, Fine1 sample presented fractures in bonding zone, which is not an appropriate fracture location. Therefore, although Fine1 sample has good consumables, their brazing was not well performed. This evidences the necessity of developed standard procedures for quality assurance of destructive tools.

Table 5. Absorbed energy during modified Izod test

| Sample | Absorbed energy (J) |
|---|---|
| Fine1 | $16.2 \pm 5.4$ |
| Fine2 | $6.5 \pm 3.4$ |
| Fine3 | $5.2 \pm 1.9$ |
| Coarse1 | $22.5 \pm 12.9$ |
| Coarse2 | $5.0 \pm 0.7$ |
| Coarse3 | $4.6 \pm 4.9$ |

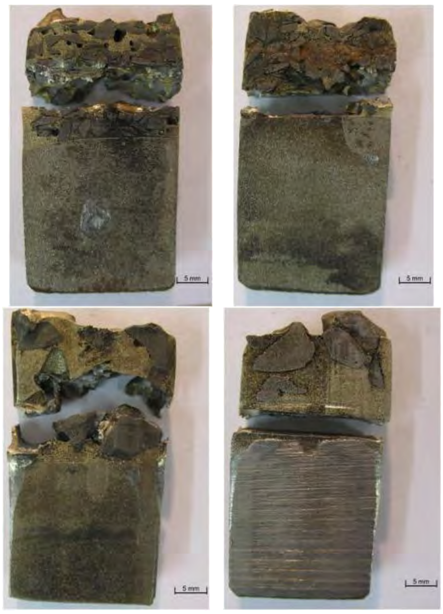

Figure 9. Fracture locations - left: inside the deposit (suitable) and right: in the bonding zone (inappropriate); observed for fine (top) and coarse (bottom) granulometries

Table 6. Fracture locations for different granulometries and samples

| Samples | Trial 1 | | Trial 2 | | Trial 3 | |
|---|---|---|---|---|---|---|
| | BZ | IBD | BZ | IBD | BZ | IBD |
| Fine1 | | x | x | | x | |
| Fine2 | x | | x | | x | |
| Fine3 | x | | x | | x | |
| Coarse1 | | x | | x | | x |
| Coarse2 | x | | x | | x | |
| Coarse3 | x | | x | | x | |

BZ is Bonding Zone and IBD is Inside Brazed Deposit

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## 4. STANDARD PROCEDURE FOR SIMULATIVE TEST

After consumables acceptance and production procedures are qualified, the final step is the development of a simulative test in laboratory conditions to assess different set of parameters (granulometry, suppliers, welders, production processes, etc) on the final performance of the destructive tool. Therefore, a physical simulative test is proposed with the construction of dedicated instrumented rig as shown in Figs. 10 and 11 (Vilarinho et al., 2005). This rig is capable of maintaining constant force between 150 a 500 kgf with rotation speed up to 300 rpm. As comparison, in offshore destructive operations forces range from 1500 kgf to 20,000 kgf and rotation between 50 and 150 rpm (Charminar, 2010 and Parveen, 2010). Thus, rotation is at comparable values, but forces due to structural limitation are lower. This feature leads to longer runs, but with comparable results to field trials (Vilarinho et al., 2005).

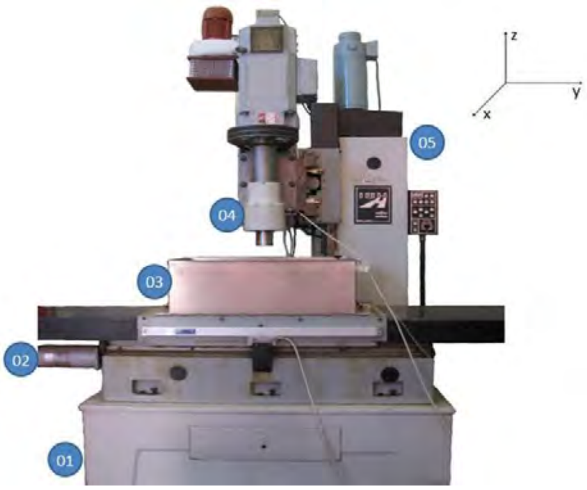


Figure 10. Simulative rig: 01 – Fluid reservoir; 02 – Y axis; 03 – Tank; 04 – Dynamometer; 05 – X and Z axis

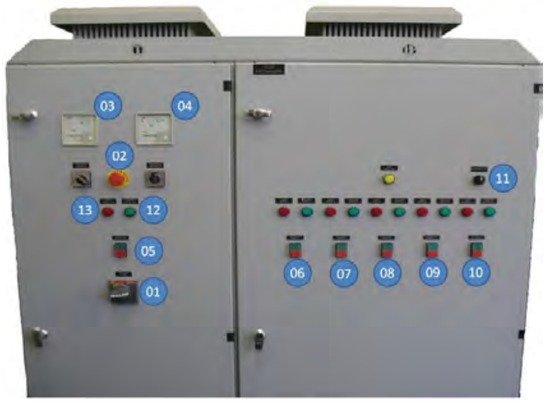


Figure 11. Electric board: 01 – On/Off; 02 – Emergency stop; 03 – Voltage reading; 04 – Current reading; 05 – Rotation motor; 06 – X axis; 07 – Y axis; 08 – Z axis; 09 – Pumping system; 10 – Heating system; 11 to 13 – Automatic mode

Both Z axis force and torque are monitored by a developed dynamometer fixed to the Z axis with brushed for data acquisition. Force monitoring is required since runs are carried out at constant force and when the deposit wears out the Z axis must be push down by the rig to automatically keep the same force. Torque is monitored so when the brazed deposited is wear out the torque falls down to approximately zero and the axes are moved to another position in the plate, so different trials can be carried out in one same plate.

Test plate is the same one for image processing from the standard procedure for product assessment. The plate is laterally clamped inside a tank (Fig. 12), which is filled up with fluid (water or perforation fluid, as desired) and then heated up by electric resistances. User sets the temperature in the control panel (Fig. 13), which is automatically controlled. The same software interface is used for inputting the desired force and rotation to be kept constant during the run. Figure 14 brings a schematic view of the rig. Once parameters are set in the user interface, the operator sets the electric board to automatic mode and starts the software and the experiment is carried out with no user interference.

Also in Fig. 12, it is possible to observe that a “sacrifice” metal, here called coupon, is attached to the dynamometer. This coupon is made of SAE 1045 carbon steel quenched in oil with dimensions shown in Fig. 15 and its hardness reaches 48 ± 3 HRc (497 HV). Because of long duration of runs (from four to eight hours), the coupon needs to be quenched to better resist against the carbides in the plates.

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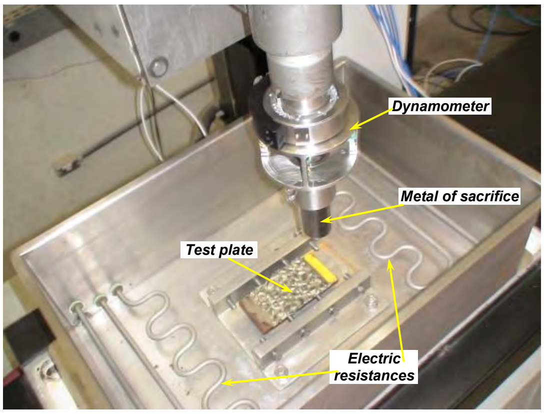


Figure 12. Detail of the tank with clamping system for the sample, heating resistances and dynamometer over the tank

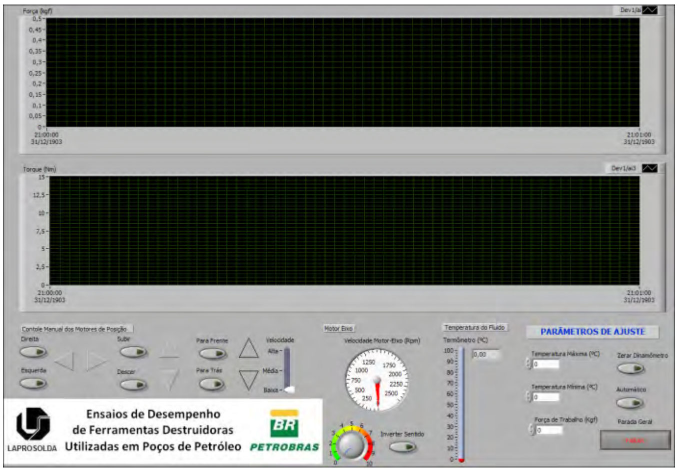


Figure 13. User interface

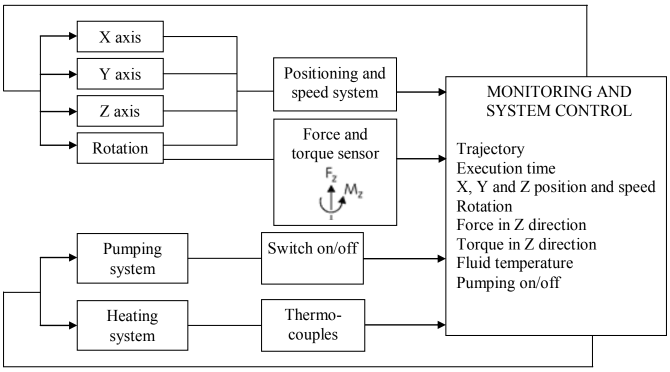


Figure 14. Schematic view of information flow in the rig

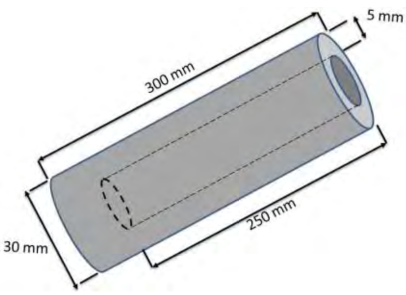


Figure 15. Employed coupon (sacrifice metal) dimensions

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Finally is worth mentioned that, differently that happens in offshore operation, the developed rig rotates the fish (in this case the coupon/sacrifice metal) while keeps the brazed deposit fixed. Since speed is relative, it is assumed here to be a valid proposition.

For both granulometries under studied in this work, water was used as fluid and temperature was set in 80 ºC. Force was kept constant at 150 kgf. The total time for one run is four hours and wear is measure by mass decrease every 30 minutes. Two rotations were investigated: 75 and 150 rpm. As example, Fig. 16 shows results for force monitoring.

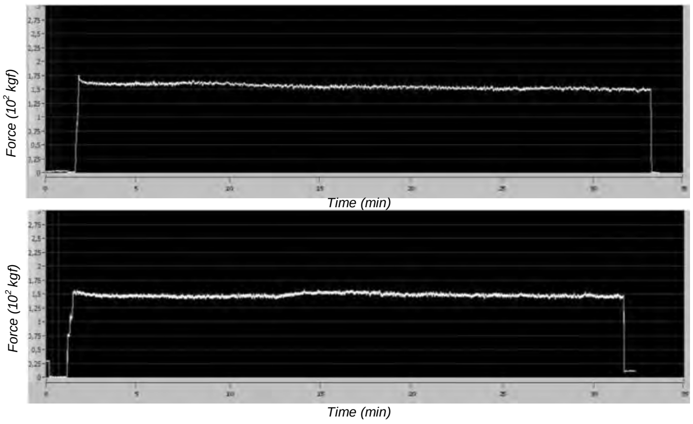


Figure 16. Force variation during simulative test for granulometries fine (top) and coarse (bottom) at 150 rpm

Wear of both test plate and coupon after four hours of testing can be seen in Fig. 17, as example. There is a constant decay of mass for both plate and coupon. For the test plate there is a tendency of lower decay in its mass after 180 min. This is due to the loss in sharpness of edges of carbides. The final results for mass loss are shown in Tab. 7.

From Table 7 it is possible to confirm that a fine granulometry (carbides with sizes from 2 to 4 mm) with 75 rpm of rotation provided the best results (highest coupon mass loss and lowest plate mass loss). This is an evidence of previous results from standard procedures for consumable acceptance and production assessment. The only fail for fine carbides happens during modified Izod testing when fractures were notice at bounding zone. However, since compression and not tension is applied during the wear, this feature had a minor importance for the proposed standard procedure for simulative test.

Finally, it is important to point out that the proposed simulative test identified the best granulometry (fine) and rotation (75 rpm) to increase the mass loss of the coupon, which represents the mass loss in the stuck part inside oil well. Therefore, the simulative test proved as important tool for developing more efficient destructive tools.

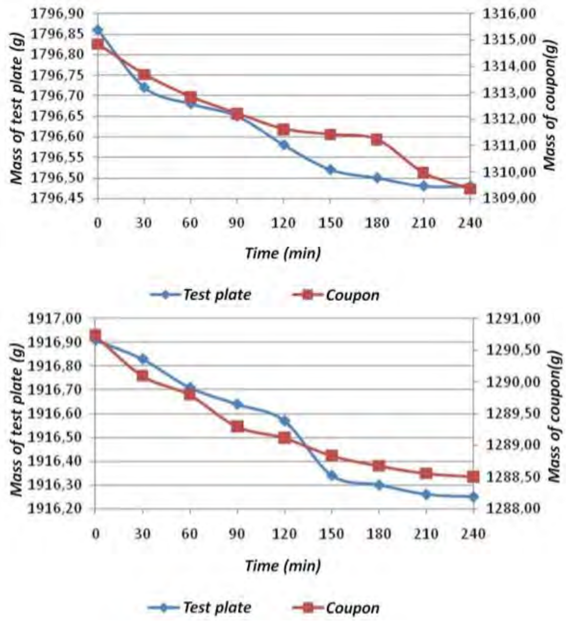


Figure 17. Mass loss as function of time for fine (top) and coarse (bottom) granulometries at 75 rpm

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Table 7. Mass losses after four hours for test plate and coupon as a function of granulometry and rotation

| Rotation (rpm) | Granulometry | Coupon mass loss (g) | Test plate mass loss (g) |
|---|---|---|---|
| 75 | Coarse | 2.06 | 0.43 |
| | Fine | 2.94 | 0.29 |
| 150 | Coarse | 2.98 | 1.00 |
| | Fine | 3.16 | 0.24 |

## 5. CONCLUSIONS

From the three developed approaches for assuring uniformity and quality during manufacturing of destructive tools, it is possible to conclude that:

a) For the proposed standard procedure for consumable acceptance:

• Gravimetry measures the WC-Co mass percentage in the consumable rods;

• The image processing algorithm identifies uniform crushed carbides distribution in the rods, separating them into good and bad consumables.

b) For the proposed standard procedure for production assessment:

• The developed image processing tool measures uniform distribution of tungsten carbides over the brazed deposit during a standard deposition procedure with a give plate size;

• The modified Izod test is capable of calculating the absorbed energy of the brazed deposit and defines the fracture location (inside the deposit, which is acceptable and in the bounding zone, which is inappropriate).

c) For the proposed standard procedure for simulative test under laboratorial conditions:

• The developed rig is capable of simulating the destructive operation and the best results were achieve with fine carbides and rotation of 75 rpm, which led to the highest coupon mass loss and lowest test-plate mass loss.

d) As dedicated standards that cover the presented aspects for this operation was not found, it is expected that the standard procedures presented in this work can be used for discussing this subject and could help developing new standards for oil and gas sector, especially in Brazil, as the pre-salt fields will demand more and more offshore exploration.

## 6. ACKNOWLEDGEMENTS

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