1. Introduction

The deep and directional drilling process frequently uses aluminum – alloy drill pipes. Two such types of drill pipes are mainly utilized throughout the world, as shown below:
- internal-flush drill pipes;
- aluminum-alloy drill pipes accommodating tool joints to be screwed to them.

The research activities carried out within The Oil & Gas University of Ploiesti and based on collaboration with users who represent the Romanian oil industry made the selection of a certain variant of drill pipe to be possible. The 3 ½ inch (88.9 mm) aluminum-alloy drill pipe with screwed steel tool-joints was selected (Figure 1).

Fig. 1. Aluminum-Alloy Drill Pipe with Screwed Steel Tool-Joints

The connection shape and manufacturing conditions are chosen to achieve a maximum resistance to static loading (tension, bending, torsion) and to the dynamic one (fatigue resistance).

The assembling between tool joints and the pipe body is a shrink – fit type that provides a pressure-tight assembly and efficient transfer of tension, torsion, bending and compression loads between pipe and steel connection.

The connection shape is a triple-blockage one as show in Figure 2.

Fig.2 The Connection with “Triple-Blockage” between Aluminum-Alloy Drill Pipe and Steel Tool-Joint

Fig.3 Screw -Thread Profile of the Tool Joint-to-Drill Pipe Connection (3 ½ inch size)
This connection is a shrink-based one making controlled tightening possible on three surfaces simultaneously, namely:
- on the surface $S_1$ of the taper thread featuring trapezoidal profile;
- on a flat cylindrical surface $S_3$ following the thread;
- on a front surface $S_2$ existing between the drill pipe and special shoulder inside the tool joint.

The present experience shows a significant aspect related to the manufacture and use of the aluminum-alloy drill pipes. Therefore, the most recommended materials are the alloys being machinable by plastic deformation and structurally hardenable due to the application of the heat-treatment cycles. The aluminum-alloys capable of plastic deformation and susceptible of structural hardening due to the application of the heat-treatment cycles has a complex chemical composition which is determined by a series of needs regarding the following:
- machinability improvement induced through plastic deformation;
- elimination of the negative effect exerted by those impurities whose removal is difficult during the melting process;
- hardenability increase induced through the quenching process;
- corrosion-resistance improvement.

The Romanian manufacturers selected the aluminum alloy 2024 to fabricate the prototype of the drill pipe; its Romanian equivalent is AlCu4Mg1.5Mn in compliance with the STAS SR EN 573-3/1995 requirements.

The aluminum-alloy drill pipes are equipped with steel tool-joints made of 34MoCrNi15, subjected to a heat-treatment cycle consisting of quenching and tempering.

Manufacturing the prototypes of the aluminum-alloy drill pipe means:
- designing the threaded connection (the thread of the drill pipe as well as that of the tool joint);
- elaborating the processing technology for the two elements;
- designing the screwing technology and equipment;
- designing a stand to permit the endurance test to be applied (rotary fatigue endurance) because the said test is the only one that can validate the constructive solution and the designed technology.

All above-specified problems required a solution.

This paper shows several of the above mentioned aspects, namely:
- technological problems related to how to cut the threads on the body of the aluminum-alloy drill pipes;
- technological problems related to how to cut the thread of the steel tool-joints and the body of the aluminum-alloy drill pipe.

2. Machining Operations Applied to The Ends of The Extruded Aluminum-Alloy Pipe – Technological Problems

2.1. Research Concerning The Influence of the Cutting Parameters on Precision and Roughness

The ends of the aluminum-alloy drill pipes shall be machined under adequate conditions so that the dimensional precision and quality parameters might be achieved, especially in the case of the surfaces of those flat threaded zones. In this way, the tool joints can be screwed to the drill pipes or the drill pipes can be screwed one to another.

Those above required the main specific conditions related to the cutting machinability of those alloys to be known.

If the finish and threading turning operations are the only ones that have been taken into consideration (main machining operations for the matching surfaces of the ends of the aluminum-alloy drill pipes), the following problems shall be considered:
- machining the respective ends under optimum conditions means using carbide-tipped tools type K10 or K20 and sharpened for a minimum roughness value of the cutting edge (R\textsubscript{a} < 2 µm); in case of the threading tools, the cutting edges should be lapped, abrasive paste of 50…100 µm and a cast-iron disk should be used;
- the desired quality features of the machined surfaces may be obtained by meeting the following conditions when the tools are sharpened and positioned:
  • radius at the tool apex, r ≥ 0.5 mm;
  • rake angle, \( \gamma = 25…30^\circ \); a cutting channel shall be machined on the rake surface;
  • relief angle, \( \alpha = 5…7^\circ \);
  • primary attack angle, \( \chi = 40…80^\circ \);
  • secondary attack angle, \( \chi_1 = 40…80^\circ \);
- the threading tools have cutting ends profiled in compliance with the thread type being to be cut; the cutting-edge shape shall be corrected in compliance with the rake angle \( \gamma = 25…30^\circ \).
- the machined surface must have an adequate roughness if the applicable cutting cycles involve the following:
  • small depths of cut (t ≤ 0.5 mm);
  • small feeds and speeds either very small or great so that any settlement might not occur on the cutting edge; in the case of threading, small cutting speeds (v ≤ 50 m/min) are recommended for the first passes and a cutting speed (v) of 12…15 m/min if the thread is to be finished;
- meeting the adequate quality requirement for the machined surfaces requires cooling and lubricating fluids to be used for the cuttings removal so that no cuttings fragments might adhere to the rake surface of the tool; cooling and cutting emulsions are recommended, that contain 17 per cent of water or oil; in case of their lack, the cooling-free machining operation shall be preferred.

The above-shown technical recommendations were checked through experimental research activities regarding the influence of the machining process on the quality requirement for the surfaces externally machined by taking-finishing operations. The research was made on the prototype drill pipes designed by the Oil & Gas University. The chemical composition and mechanical properties of that alloy are shown in Table 1.

### Table 1

<table>
<thead>
<tr>
<th>Alloy Type and Heat-Treatment State</th>
<th>Chemical Composition, %</th>
<th>Mechanical Properties</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cu</td>
<td>Mg</td>
</tr>
<tr>
<td>2024 – T851</td>
<td>4.24</td>
<td>1.40</td>
</tr>
</tbody>
</table>

To the drill pipes (made of alloy 2024 and belonging to the studied batch) was applied a heat-treatment cycle consisting of the following steps:
- quenching:
  • heating into a vertical furnace at 495 ± 5\(^\circ\) C;
  • maintaining to the temperature for 30-40 min;
  • temperature of the water cooling at 40\(^\circ\)C;
- elongation of 2 per cent by strain hardening;
- artificial aging:
  • heating at 190 ± 5\(^\circ\) C;
  • maintaining for 12 hours;
  • air cooling.

The metallurgical state was symbolized by T851. During the experiments a carbide-tipped tool type K10 was used and the threading tool had the following geometry:
\[ \gamma = 25^\circ, \ \alpha = 5^\circ, \ r = 0.5 \text{ mm} ; \ \chi = 50^\circ, \ \chi_1 = 10^\circ \]

The machining operations were performed without cooling. The results of the above specified research activities are shown in Figure 4.

The curves prove how roughness varies with the cutting speed and point out the fact that all prior prescriptions are really valid (curves of the roughness variations).

2.2. The Threading Tool

During their working life, the drill pipes are greatly influenced by the quality of the threads. The rake surface represents a significant aspect of the threading operation and a factor of great impact of the dimensional precision. A \( \gamma \) of \( 25...30^\circ \) is considered to be the optimum value of the said rake surface utilisable when aluminum-alloys are processed. When the threading tools have \( \gamma \neq 0 \), the tool profile occurring in the plane of the recessing surface does not correspond to the profile of that thread whose flanks are straight. The profile of the cutter is determined on the basis that the tool width contacting of the relief surface is equal to the width of the space existing between the thread turns.

To calculate the displacements \( \Delta m \) for half profile and the displacements \( \Delta e \) at the thread head crest (Figure 5) it is necessary to know the angles \( \theta_m \) and \( \theta_e \). These angles are determined from the triangles Oim and Oie (Figure 6) through the following relations:

\[
\sin(\gamma-\theta_m) = \frac{r_m \sin \gamma}{r_i} ; \ \sin(\gamma-\theta_e) = \frac{r_e \sin \gamma}{r_i} ; \quad (1)
\]

where \( r_i, r_m, r_e = \) radii corresponding to the base, mean diameter and crest head of the thread.

When the values of the angles \( \theta_m \) and \( \theta_e \) are known, the values of the displacements \( \Delta e \) and \( \Delta m \) may be calculated if the following aspect is considered: a complete rotation generates a displacement equal to the propeller pitch, \( p \).

\[
\Delta m = \frac{\theta_m p}{360^\circ} ; \ \Delta e = \frac{\theta_e p}{360^\circ} ; \quad (2)
\]

The above-specified triangles Oim and Oie also permit the calculation of the distances \( im \) and \( ie \) on the relief face, the following relations being used:

\[
im = r_m \frac{\sin \theta_m}{\sin \gamma} ; \ \ iei = r_e \frac{\sin \theta_e}{\sin \gamma} ; \quad (3)
\]

The above data permit the profile of the threading tool to be contoured in the plane of the relief surface.

The application of the above methodology allows the profile of the threading tool to be determined, i.e., that tool being used for threading aluminum-alloy pipes representing the body of the drill pipes. The value of the tool are shown in Figure 6.

The above prescriptions related to the aluminum alloys to be cut for roughness values equal to 3.2 to 12.5 \( \mu \text{m} \) are also valid in the case of the threading operation.
When the aluminum-alloy drill pipes are machined, another aspect to be taken into consideration is to protect those surfaces that are gripped through the devices being used for gripping. The said protective action shall be implemented to permit the pipe material to be protected against the traces left by the grips of the lathe chuck because the respective traces can represent stress concentrators that influence the pipe endurance property negatively.

### 3. Technological Problems Occurred When The Steel Tool-Joints are Screwed to The Body of the Aluminum-Alloy Drill Pipes

#### 3.1. Statement of The Screwing Parameters

Performing the assembly between the pipe body and steel tool-joints so that a present tightening value might be obtained requires a certain technology to be adopted, the respective technology consisting in:
- heating the steel tool-joint;
- screwing;
- cooling.

The selection of the working parameters is determined by the need of avoiding any modification of the heat-treatment cycles applied to the components to be assembled one to another.

A heat-treatment cycle consisting in quenching at 850°C and tempering at 600...620°C is applied to the steel tool joint made of 41MoCrNi15. Therefore, when the tool joint is to be screwed, the heating temperature does not reach the tempering one. As proved experimentally, the heat treatment cycles applied to the aluminum-alloy pipe also include artificial aging generated at 190°C. As a result of those above, during the assembling process, it becomes necessary for the pipe inside to be intensely cooled (i.e., the matching zone) so that the aluminum-alloy overheating and alteration of the general mechanical properties induced through the heat-treatment cycle might be avoided. The procedure consisting in cooling the pipe with liquid nitrogen is selected so that the pipe shrinkage might be obtained that facilitates the screwing step due to the higher degree of clearance occurred between two parts.

Performing the screwing step more easily, the following aspects are taken into account when the working parameters are to be started:

- the value of the tightening as it has been carried out shall be compensated on the basis of the tool-joint expansion, the tool joint having to be heated at an adequate temperature;
- the clearance necessary for the components to be easily and rapidly screwed is to be obtained due to the pipe shrinkage after it is cooled with liquid nitrogen;
- the screwing stand shall permit all steps for a rapid screwing operation achieved as rapidly as possible to be performed.

The research activities are accomplished as shown for the drill pipes of 3 ½ inch. The dimensions of the tool joint and aluminum-alloy drill pipe are so preset that a diametral tightening of 0.4 mm might be provided: this value is considered to be the optimum one from the point of view of the induced stress gained as a result of the screwing operation if the fact that the materials of the pieces to be matched feature different mechanical properties is taken into account. For example:

- aluminum-alloy drill pipe made of 2024 - T851: \( R_{p0.2} = 443 \text{ N/mm}^2 \) and \( E = 7,54 \times 10^4 \text{ N/mm}^2 \);
- tool joint: \( R_p = 820 \text{ N/mm}^2 \) and \( E = 20,6 \times 10^4 \text{ N/mm}^2 \) [1].

The value of the temperature variation (\( \Delta t \)) used for heating the steel tool-joint is calculated through:

\[
\Delta t = \frac{\Delta l}{\alpha_t l}
\]

The radial-tightening value to be obtained as well as the value of the linear-expansion coefficient for steel (\( \alpha = 12 \cdot 10^{-6} \text{ grad}^{-1} \)) being taken into consideration and where:

- \( \Delta l = \) expansion value (equal to the tightening value \( S = 0.4 \) mm);
- \( l = \) initial value of the outer diameter (\( d = 100 \) mm);
- \( \alpha_t = \) linear-expansion coefficient.

If the values of the quantities for the relation (4) are taken into account, the \( \Delta t \) value is below:

\[
\Delta t = \frac{0.4}{12 \cdot 10^{-6} \cdot 100} = 375^0 \text{ C}
\]

When the screwing operation is accomplished, the temperature of the environment is about 20...25°C. For \( \Delta t \) is adopted a value of 400...410°C. This temperature provokes neither structural
modifications nor modification of the mechanical properties for the material of the tool joint, if the parameters of the quenching and tempering steps are taken into consideration.

Fitting the tool joint to the drill pipe under adequate conditions requires the following aspects to be seriously considered:

- the tightening value;
- a simultaneous contact of the three matching surfaces S1, S2 and S3 of the connection shall be provided;
- the sealing material shall be uniformly distributed within the respective connection;
- a high value of the connection fatigue endurance shall be obtained.

The customary solution specific to the aircraft-construction field is adopted for sealing (the said field uses mastic for sealing) so that the following may be obtained:

- tightness increase for the thread connection existing between the aluminum-alloy drill pipe and steel tool-joint;
- the danger of local corrosion that might occur at the contact between two different materials is avoided.

The various types of mastic are obtained on the basis of several synthetic resins that also make the assembled components be electrically insulated. In the event of the use of drilling fluids containing oil, the respective type of mastic shall be resistant to oil products. The PR1431 and PR1422 class A types of mastic are recommended to be utilized due to their range of working temperatures (−55°C to 135°C) that is in compliance with the requirements shown in [1, 3].

3.2. Stand To Fit The Drill Pipe and Tool Joint

Applying the above described fitting technology requires a special stand to be designed and fabricated. The scheme of the respective stand is shown in Figure 7., where a certain step of the technological process of fitting is suggested, namely the retrieval of the electric furnace after it heated the tool joint before its assembling).

![Fig.7. Scheme of The Stand To be Used When The Tool Joints Are Screwed to The Body of The Drill Pipes](image)

As results from Figure 7, the whole stand is mounted on a SN300 normal lathe, so that all steps of the screwing-on operation are easily achieved.

The tool joint (1) is gripped by the grips of the lathe chuck and the pipe (2) is fixed in a device (3) installed on the support (4) of the holder. Fixing the pipe is possible due to several rubber rings so that any plastic deformation of the tubulars is avoided when the pipes are gripped.

Heating the tool joint at a temperature value of 400°C is feasible by means of an electric furnace (5) fixed on the lathe bed through a supporting plate (6). The control of the furnace and
tool joint temperature may be carried out by means of a device (7) permitting the electric and thermic parameters to be regulated and measured.

Cooling the aluminum-alloy pipe (i.e., the thread zone) and heating the tool joint are simultaneous, because the pipe construction is intended to be utilized for making clearance occur that facilitates the screwing-on operation; the fact that the respective connection is a triple-blockage one is so taken into consideration (2).

The assembling operation for the research activities require the pipes to be cooled with liquid nitrogen stored into a special vessel (Dewar-type recipient) and brought to the cooling place through a heat-insulated copper pipe symbolized by (8) within the stand scheme. Dosing the liquid nitrogen to be transported towards the cooling zone requires a hand pump to be used, that holds a certain pressure value into the nitrogen-containing vessel. The threaded zone of the pipe is protected during the cooling step by means of a stuffing box (9), whose walls are heat-insulated with mineral wadding (10).

The temperature values range between –100 and -80°C during the screwing-on operation. The measurements are carried out by means of a thermocouple (not shown in the scheme).

When the temperature of the tool joint reaches the prescribed value (i.e., 400°C) and the pipe end gets cooled at –100°C, the stuffing box (9) is opened, the furnace (5) is retrieved and the screwing-on operation itself is performed by rotating the lathe chuck at its smallest speed. Displacing the pipe feasible by means of the carriage, the hand feed should be utilized.

The sealing paste shall be brushed on the pipe thread before the beginning of the screwing-on operation.

The screwing-on operation comes to an end when the pipe begins to rotate (due to its elastic fixture within the device).

Cooling the pipe shall be continuous after screwing-on operation because the temperature of the pipe material may not exceed the limit admitted by the heat-treatment cycle.

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