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Research Article

Investigation of tribotechnical and corrosion behaviour of material for light-alloy drill pipes

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Abstract

Special aluminum alloys appear to be promising materials for manufacture of high-strength light-alloy drill pipes (HSLADP) that can be used in areas with a severe climate and challenging geology. The effect of using light-alloy drill pipes (LADP) depends directly on the properties of the aluminum alloys from which such pipes are made. As the wells become deeper and horizontal wellbores get longer, use of LADPs becomes more relevant. Since light-alloy pipes are 2.8 times softer than steel pipes, LADPs offer the same performance as steel drill pipes of the lowest strength grade even in the case of rotary drilling. The materials from which such pipes are made have a number of unique advantages: extra light weight in the drill mud, allowing the coefficient of sliding friction between the pipe surface and the borehole wall to be reduced; high corrosion resistance in aggressive media with A high concentration of hydrogen sulfide and carbon dioxide; and high magnetic inductive capacity that allows LADPs to be used as a housing for MWD (measurement while drilling) and LWD (logging while drilling) telemetry systems during well-drilling operations. This study suggests methods for industrial production of submicrocrystalline (SMC) structure in aluminum alloys with the help of severe plastic deformation. Through the example of model aluminum-lithium alloys 1420 (Al-Mg-Li-Zr) and 1460 (Al-Cu-Li-Zr), the researchers demonstrate that SMC structure helps significantly increase resistance to wear and reduce the rate of corrosion depending on the pH value. The research team also states that severe plastic deformation methods may be used to develop highly promising technologies for manufacture of high-strength LADPs with advanced strain-stress properties for use during operations in the Arctic.

Keywords

light-alloy drill pipes, tribotechnical tests, corrosion of aluminum alloys, Arctic shelf, horizontal drilling

Current evolution of drilling technologies and aggravation of geological and climatic conditions for drilling operations caused by the development of hydrocarbon deposits in the Arctic shelf leads to an increase in operating and maintenance costs associated with well-site construction. Reliable performance of drilling equipment and tools, specifically drill pipes, is an essential aspect that well drilling and operating performance indicators depend on. Drill pipes play a key role in the stress behaviour of rock cutting tools. The current trend of increasing the length of wells also leads to a higher probability of complications and accidents, which increases the overall cost of construction. Reliable performance of drill pipes depends on their proper use during drilling and transportation, which is achieved by timely quality control and withdrawal of deficient pipes from service. One effective way of improving performance of drill pipes, including light-alloy drill pipes (LADPs), involves development of advanced technologies for production of improved structure of aluminum alloys used to manufacture LADPs, as well as modification of drill fluids with special doping agents for the entire drilling cycle.

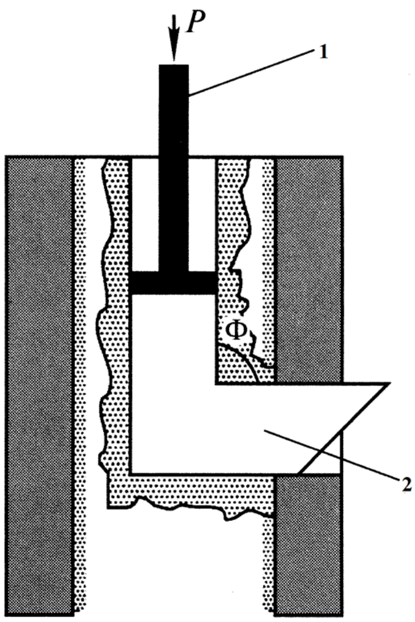

Fig. 1. Diagram of equal channel angular pressing: 1) piston, 2) pipe strip

Implementation and improvement of the techniques used for production of fine-grain materials of such alloys, as well as assessment of the state of light-alloy drill pipes by simulating their performance in the well, is essential for higher credibility and better forecasting of their performance under real-life conditions and for meaningful estimation and planning of construction of long horizontal wells.

Real-life experience shows that such wells cannot be drilled without using high-strength light-alloy drill pipes (HSLADP) manufactured from special aluminum alloys (Fain 1990, Basovich et al. 2003, Basovich et al. 2015, Shammazov et al. 2000). Pipe strips are manufactured by extrusion from the Al-Cu-Mg D16T alloy, with subsequent hardening and natural ageing (T). Where increased strength and corrosion resistance requirements apply, the pipes are manufactured from the Al-Zn-Mg 1953T1 alloy subject to hardening and artificial ageing (T1). Based on specific requirements, pipe strips are manufactured from the AK4-1T1 alloy.

Relying on the existing classification, all pipe materials can be formally divided into three classes: ultra-fine grain (UFG) with grain size of 1 to10 um, submicrocrystalline (SMC) with grain size of 0.1 to 1 um, and nanocrystalline (NC) with grain size below 100 nm. This classification is justified because the strain-stress behaviour of the UFG, SMC and NC alloys varies markedly. For instance, alloys with UFG structure demonstrate structural superplasticity in certain sections of the temperature-strain rate curve, while reduction of the grain size to nanocrystalline values in composite and mechanical alloys leads to the effect of high-strain rate superplasticity (Valiev et al. 1988, Valiev and Tsenev 1990, Tsenev 1996, Valiev et al. 1997). It has been proven that SMC and NC structures can be used to manufacture high-strength materials (Furukawa et al. 1996, Furukawa et al. 1997). Even such structurally insensitive parameters as Curie and Debye temperatures, modulus of elasticity, saturation magnetic moment, etc. are prone to change in these materials. These findings indicate that scientists can develop new advanced technologies for production of aluminum alloys used in the manufacture of HSLADPs with improved mechanical properties that will demonstrate better performance in longer horizontal leads from the vertical borehole.

This study uses an example of model commercial aluminum-lithium alloys to demonstrate the techniques of producing pipe strips with SMC structure. Experimental results obtained during the research are used to suggest that HSLADP manufacturers jointly develop advanced technologies for the production of such drill pipes with improved mechanical properties and corrosion resistance for use in different geological settings, including in the Arctic.

Materials and methods

The material used for the research was represented by model commercial aluminum-lithium alloys 1420 (Al-5.5% Mg-2.2% Li -0.12% Zr) and 1460 (Al-2.5% Cu-2.2% Li -0.12% Zr). Originally, after casting and prior to severe plastic deformation (SPD), the alloy had a coarse-grain structure. Mean grain size in the alloy was 5 mm (Fig. 4a)

Submicrocrystalline structure was obtained by equal channel angular pressing (ECAP) method (Wang et al. 2003, Kaibyshev et al. 1984). The diagram of the pressing process based on this method is provided in Figure 1. The method relies on shear deformation, with severe plastic deformation along the surface of channels intersection. To obtain the SMC structures, the ECAP process must be repeated eight times on one sample.

Transmission electron microscope (TEM) JEM-2000 EX was used for optical microscopic evaluation of samples produced with the help of this technique.

Experiment results

Shaping of alloy structure during severe plastic deformation

Fig. 2 presents the findings of investigation into the structure of alloy 1420. You may see that the original microstructure of a strained bar of aluminum alloy 1420 shows severe inhomogeneity. Its structure is made up of coarse grains elongated along the direction of pressing, with clusters of fine recrystallised grains around them (secondary phase). The mean size of the fine grains is approximately 5 um. The size of coarse elongated grains is 168 um lengthwise and 19 um crosswise (Fig. 2a).

The ECAP process at 325°C to the true deformation degree (~8) creates an almost recrystallised structure, meaning that the secondary phase dissolves in the grain, and we no longer see the clusters of recrystallised grains at the boundaries of the coarse grains (Fig. 2b). In most grains, the boundaries have a distinct outline, which means that we have obtained an equilibrium recrystallised structure. The mean density of dislocations in the grain body is small (approximately 6×10^{14}).

Wear testing of aluminum alloy

Tests on the friction machine showed interesting results with regard to the influence of SMC structure on wear processes (Valiev et al. 1986, Shakinova et al. 2017). Laboratory tests were carried out at room temperature (T=293K). The base material (used for reference) was represented by a coarse-grain alloy with an original grain size of D_0=5mm. The reference piece was made from steel 40X. The alloys were subject to tests on a specialised test bench allowing a rocking motion of the samples to make sure the process of wear on casings and drill pipes in laboratory conditions resembles the real-life wear process during RIH/POH operations. Lubrication and cooling was achieved by immersing the friction zone in a bath with a drill fluid made from a polymer mud solution with different concentrations of lubricating additives: Lubriol, Eco Lube, FK200, AKS303. The results of tribotechnical tests of the alloy with different structures are provided in Fig. 3.

Fig. 3 shows that the wear rate for alloy 1420 largely depends on the grain size and condition of the grain boundaries. The wear on the reference piece was not taken into account. You may see that reduction of grain size to 0.5 um makes the alloy over two times more (on average) wear-resistant in all the tested media compared to the original coarse-grain alloy (D_0=5mm).

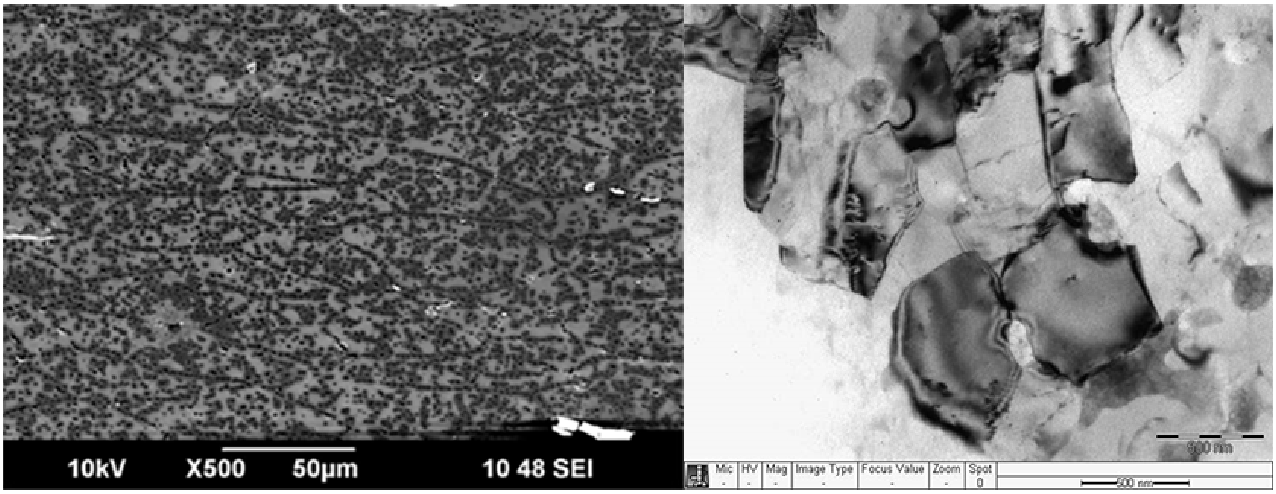

Fig. 2. Structure of alloy 1420: a) macrostructure of original sample; b) alloy's microstructure after ECAP severe plastic deformation

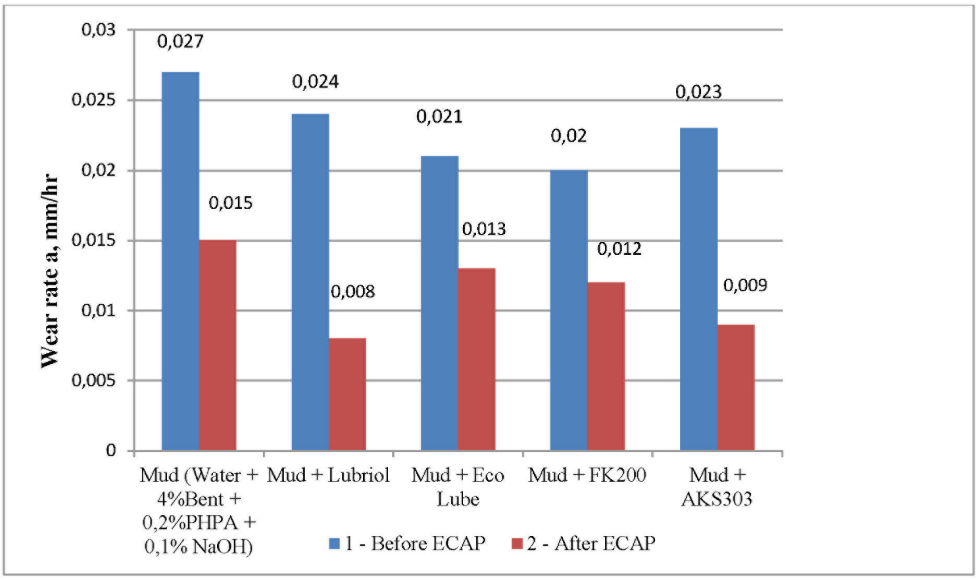

Fig. 3. Wear rate for alloy 1420 samples with coarse grain and SMC structure at T=293 K in drill fluid with different lubricating additives (confidence intervals established at 80% probability). (These results were obtained on friction machine UMT-2168)

Corrosion test

The gravimetric (visual) method was used to assess the alloy's corrosion in the laboratory using the following test sample: aluminum alloy 1460 (Al-Cu-Zr) before and after treatment, and pure aluminum. The pH rate of the test medium to which the surface of the samples was exposed varied from 7 to 11. The test medium was represented by a biopolymer drill mud (BDM) with the following formula: Water + Na2CO3 0.1% + NaOH 0.1% + Bactericide 1.5% + PAC LD 0.4% + Xanthan gum 0.8% + Lubricating additive 5%.

1) ph=7 – BDM;
2) ph =8 BDM + NaOH 0.1 ml;
3) ph =9 BDM + NaOH 0.2 ml;
4) ph =10 BDM + NaOH 0.5 ml
5) ph =11 BDM + NaOH 1 ml.

The following curves of weight loss versus time of exposure to aggressive media were obtained for the corresponding samples (Fig. 4).

You may see that aluminum alloy 1460 after treatment by severe plastic deformation shows a higher resistance to corrosion in alkaline medium.

Discussion

The study demonstrated that the severe plastic deformation technique (ECAP method) can be used not only to make the structure of alloys significantly (by several orders of magnitude) more compact, but also to obtain grains with different states of grain boundaries. Detailed studies of the structural changes that occur during the severe plastic deformation process showed that fragmentation of the alloy's structure takes place as a result of formation of an equilibrium recrystallised structure.

Preliminary tribotechnical and corrosion tests proved a substantial increase in wear and corrosion resistance of the material with the finer structure. It is important to note that resistance to wear and corrosion also depends markedly on the state of the grain boundaries. Fig. 3 shows that the alloy's wear immediately after severe plastic deformation is at its minimum. A metallographic examination of the alloy's structure indicates that this is caused by high inner stresses, non-equilibrium of the grain boundaries, and the size of the grains. Fig. 4 demonstrates that the alloy becomes more resistant to corrosion if appropriate material treatment methods are used to make the material suitable for service in aggressive media with a high pH value. Numerous studies

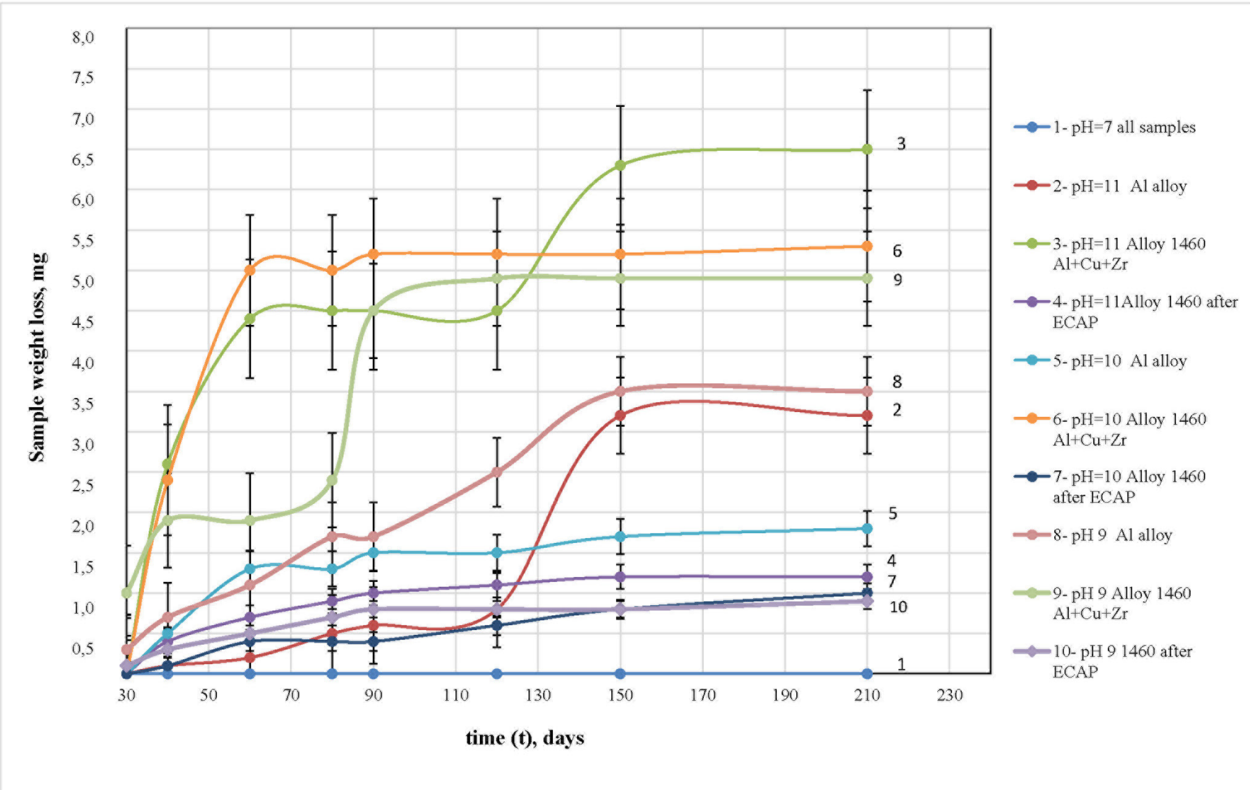

Fig. 4. Weight loss vs. time of exposure to aggressive media curves

Table 1. Mechanical properties of existing aluminum alloys D16T, 1953T1 and AK4-1T1 in as-delivered condition

Properties	Unit	Alloy grade		
		D16T	**1953T1**	**AK1-4T1**
Tensile stress, minimum	MPa	460	530	410
Yield stress, minimum	MPa	325	480	340
Brinnel hardness (500 kg, 10mm)	HB	120	120-130	120-130
Design density	kg/m³	2800		
Percentage elongation, minimum	%	12	7	8
- Young modulus	MPa*10^5	0.72	0,71	0,72
- Shear modulus		0.26	0,275	0,26
Working temperature, maximum	°C	160	120	220
Linear expansion coefficient	$°C^{-1}$	22.6×10		

have proved that hardness, breaking strength, hot strength, microstructure and corrosion resistance are the key criteria for the material's wear resistance (Makarov and Korshunov 2004, Luzhnov et al. 2016).

Thus, the study used model alloys 1420 and 1460 to demonstrate the prospects for controlling the structure of materials with the help of one of the methods of severe plastic deformation. Combining SPD methods with subsequent heat treatment, we can formulate technologies for production of light-alloy drill string elements that can be successfully employed in a variety of challenging climatic and geological conditions.

Today, aluminum alloys D16T, 1953T1 and AK4-1T1 are widely used in the production of light-alloy pipes. The mechanical properties of these materials are described in Table 1. We believe that different combinations of SPD and heat treatment techniques can help increase corrosion resistance of aluminum alloys by a factor of five and wear resistance by 30%.

To summarise the above, the relevance of the matter described in this study is growing. The authors made an assumption concerning the prospects for development of new domestic substitutes of technologies for production of high reliability light-alloy drill pipes that can be used in different geological settings, including in the Arctic.

References

- Basovich VS, Gelfgat MYa, Fain GM (2003) The current state and future outlook for using aluminum alloy products in oil and gas production. Burenie i Neft [Drilling and Oil] 4: 24–26.
- Basovich VS, Buyanovskiy IN, Petunkin IV (2015) The outlook for using aluminum drill pipes in drilling extensive horizontal wells. Burenie i Neft [Drilling and Oil] 6: 80–85.
- Fain GM (1990) Light-alloy oil pipes. Nedra, 224 pp.
- Furukawa M, Berbon P, Horita Z, Nemoto M, Tsenev NK, Valiev RZ, Langdon TG (1996) Structural evolution, ageing behavior and mechanical properties of an Al-Mg-Li-Zr alloy with ultra-fine grain size. In: Ishida Y, Morita M, Suga T, Ichinose H, Ohashi O, Echigoya J (Eds) Interface Science and Materials Interconnection. The Japan Institute of Metals, Japan, 479–482.
- Furukawa M, Berbon P, Horita Z, Nemoto M, Tsenev NK, Valiev RZ, Langdon TG (1997) Production of ultrafine-grained metallic materials using severe plastic deformation technique. Materials Science Forum 233–234: 177–184. https://doi.org/10.4028/www.scientific.net/MSF.233-234.177
- Kaibyshev OA, Valiev RZ, Tsenev NK (1984) The effect of grain boundary condition on superplastic flow. Proceedings of the USSR Academy of Sciences 278(1): 93–97.
- Luzhnov YuM et al. (2016) Choosing test configurations for friction assemblies tested on the universal friction machine UMT-

2168 UNITRIB: Methodology guidelines for laboratory practice in Triboengineering (4 parts, Part 1). MADI, Moscow, 20 pp.

- Makarov AV, Korshunov LG (2004) Strength and wear resistance of nanocrystalline structures on the friction surfaces of steel with martensitic matrix. Izvestiya VUZov [Academic Herald]. Physics 8: 65–80.
- Shakinova AI, Ismakov RA, Agluillin Akh (2017) A comprehensive study of the materials of aluminum drill pipes. Izvestiya Tomskogo Politekhnicheskogo Universiteta [Tomsk Polytechnic University Bulletin]. Geological Resources Engineering 328(2): 95–103.
- Shammazov AM, Tsenev NK, Akchurin KhI, Nazarova MN, Ismakov RA, Lebedich SP, Sukhanov VD, Chudinov BA, Krushtal MM (2000) Ultrafine-grain materials and the outlook for their use in mining and pipeline operations. Gorniy Vestnik [Mining Herald] [2000]: 33–36.
- Tsenev NK (1996) Grain boundaries structure and mechanical properties of aluminum alloys. Materials Science Forum, Intergranular and Interphase Boundaries in Materials, 207–209.
- Valiev RZ, Kaibyshev OA, Kuznetsov RI, Musalimov RSh, Tsenev NK (1988) Low-temperature superplasticity of metals. Proceedings of the USSR Academy of Sciences 301(4): 864–866.
- Valiev RZ, Tsenev NK (1990) Structure and superplasticity of Al-based submicron-grained alloys. Hot deformation of aluminum alloys. Proceedings of a symposium by the non-ferrous Metals Committee of the Minerals, Metals and Materials Society, Detroit, Michigan, October 8–10, 319–329.
- Valiev RZ, Salimonenko DA, Tsenev NK, Berbon PB, Langdon TG (1997) Observations of high-strain rate superplasticity in commercial aluminum alloys with ultrafine grain sizes. Scripta Materialia 37: 945–1950. https://doi.org/10.1016/S1359-6462(97)00387-4
- Valiev RZ, Kaibyshev A, Korznikova GF, Tsenev NK (1986) Grain boundary structure and superplasticity of aluminum alloys. FMM [Physics of Metals and Metal Science] 62(1): 180–186.
- Wang ZB, Tao NR, Li S, Wang W, Liu G, Lu J, Lu K (2003) Effect of surface nanocrystallization on friction and wear properties in low carbon steel. Materials Science and Engineering (A) 352(1–2): 144–149. https://doi.org/10.1016/S0921-5093(02)00870-5