effect than other types of transportation if a comprehensive pipeline process management system that is based on international best practices for providing protection and risk control is applied.

Modern assessments of the strength and resources of complex engineering systems present a new way for managing their performance. This can be done through the scientifically documented application of linear and nonlinear deformation and fracture techniques, risk analysis, resource justification for safe operation, and accident avoidance.

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# MECHANICAL PROPERTIES OF MAGNESIUM ALLOY FOR MEDICAL APPLICATIONS AFTER DEFORMATION TREATMENT


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There is an increasing emphasis on the development of new materials for medical applications, especially to the group of biodegradable materials. There are various biodegradable materials, but they do not meet several requirements, namely speed of resorption in the body, level of mechanical properties and biocompatibility [1-3]. The magnesium-based group of metallic materials is best suited to biocompatibility. However, these alloys have too high ~~a~~ resorption rate, which limits their widespread use in medicine [2]. In addition, magnesium alloys have low mechanical properties, which prevents their use for load-bearing applications [1].

To improve the physical and mechanical properties the researchers apply various severe plastic deformation techniques [4], which can improve the strength characteristics of magnesium alloys by refining the grain structure without significantly changing the rate of bioresorption. The rate of bioresorption can be significantly reduced by rare earth element doping of magnesium alloys using such rare earth elements as yttrium, cesium, neodymium, zirconium. Thus, the purpose of this work is to study the structure and mechanical properties of magnesium alloys based on Mg-Y-Nd system during strain treatment.

The object of the study was an alloy of the Mg-Y-Nd system alloy. The alloy was obtained by direct permanent-mold casting. The alloy was studied in extruded and recrystallised states. The extruded state of the samples was obtained by reverse pressing at a speed of 0.5 mm/s at 350 °C billet and extruder walls temperature. The recrystallized state in the alloy was obtained by annealing at 510 °C for 6 hours in argon followed by cooling in air. In two states the samples had the form of rods with diameter of 16 mm.

The elemental composition of the alloy (Mg 94.0 wt.%; Y 3.5 wt.%; Nd 2.5 wt.%) was determined by EDS analysis on a LEO EVO 50 scanning electron microscope. Vickers microhardness (Duramin-5 microhardness tester, Denmark), yield tensile strength $\sigma_{0,2}$, ultimate tensile strength $\sigma_B$ and elongation at break $\delta$ (Instron 8801 testing machine, UK) at 0.002 $s^{-1}$ were selected as mechanical properties. The microstructure of alloy samples was investigated by optical microscopy in longitudinal sections of the samples.

Microstructure images of the alloy are shown in Figure 1. In the extruded state, grains of the main magnesium phase with an average size of 14±7 μm can be observed all over the surface of the slip. Under high magnification (Figure 1c) the structure consists of two types of structural elements: grains with an average size of 14±7 μm, and smaller grains with an average size of 1 μm, which form "bands". In the case of recrystallized state of the alloy the microstructure is represented only by equiaxed grains having average size up to 35±20 μm.

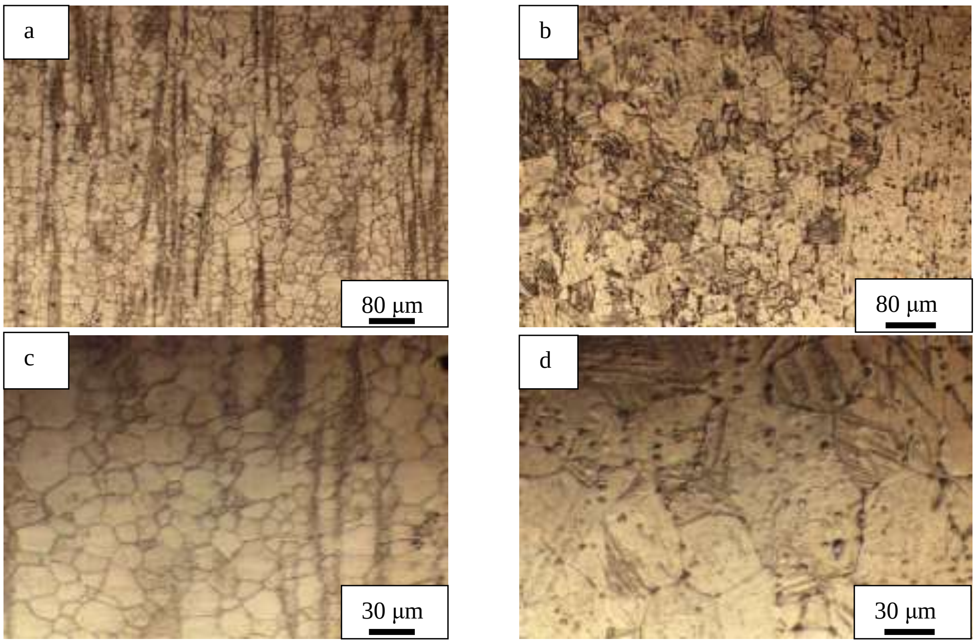


***Fig. 1. Optical images of the microstructure of alloy samples in extruded (a, c) and recrystallised (b, d) states in longitudinal section***

The phase composition in two states is represented by the main magnesium phase and the nanosized intermetallic phase $Mg_{24}Y_5$. During alloy crystallisation the size of the intermetallic phase increases from 400 to 500 nm.

Tensile curves of the alloy obtained for the investigated states are shown in Figure 2. And the table shows mechanical characteristics of Mg-Y-Nd alloy in extruded and recrystallized states. The figure also shows the dependences of the strain-hardening coefficient (θ) on the strain value (ε). The yield strength $\sigma_{0,2}$ of the extruded alloy is 125 MPa, which is 1.3 higher than for the recrystallized state, 97 MPa. The ultimate tensile strength $\sigma_B$, equal to 330 MPa, is 1.4 times higher in comparison with the recrystallized state, $\sigma_B$ = 235 MPa. The elongation at break δ for the extruded sample was 21 %, and in the recrystallized state this value was 12 %. The difference in properties is due to the peculiarities of the microstructure [5]. The "stripes" of fine grains provide the strength of the alloy, on the other hand the larger grains deform well along the stripes of fine grains.

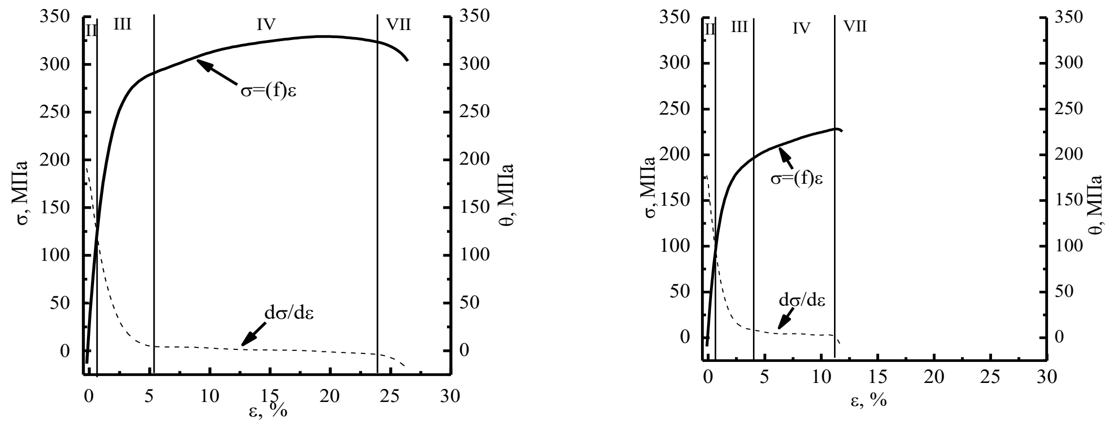


***Fig. 2. Tensile curves for Mg-Y-Nd alloy in extruded (a) and recrystallised (b) states***

***Table***

***Physical characteristics of Mg-Y-Nd alloy***

| State | Average grain size, µm | $\sigma_{0,2}$, MPa | $\sigma_{в}$, MPa | δ, % | HV, MPa |
|---|---|---|---|---|---|
| Extruded | 17±8 | 125 | 330 | 21 | 1210 |
| Recrystallised | 35±20 | 97 | 230 | 12 | 860 |

For these two states, the character of the curves is similar, but the duration of the stages is different, due to different strain values. Four stages of plastic deformation can be distinguished on the deformation curves of the alloy in the two states according to [6]. The first stage is the linear section of elastic deformation (II), in which a decrease in θ coefficient is observed. The next stage III is parabolic and occurs when the Beckofen-Consider condition is reached, the coefficient θ at this stage decreases to zero. The transition to stage IV is accompanied by a small linear segment, but the general character of the curve remains parabolic and the strain-hardening coefficient at this segment remains close to zero. Stages V and VI are absent, which can be attributed to the deformation characteristic of the material. At the final stage VII the coefficient θ drops to negative values, which is caused by low ductility of the alloy. Neck thickness during deformation process remains practically constant, so in the last stage the material sharply loosens, which leads to its destruction.

It is found that Mg-Y-Nd alloy in extruded state has higher mechanical characteristics than in recrystallized state. Under static tension, the deformation behavior of Mg-Y-Nd alloy in extruded and recrystallised states has a common pattern in terms of different relative elongation. The severe plastic deformation method is more efficient in the extruded state.

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# OIL PRODUCTION RATE PREDICTION AFTER TREATMENT OPERATIONS USING MACHINE-LEARNING TECHNIQUES

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The biggest part of the modern oil fields has poor filtration properties, so the energy industry needs new solutions in different spheres to reach economic efficiency in the process of oil extraction. One of the most widespread methods to produce hydrocarbons from tight reservoirs or facial zone with low permeability (for example, deep marine depositional environment: lobe deposit) is applying multistage hydraulic fracturing (HF) on horizontal wells.

Drilling a well and conducting workovers are connected with a high degree of risk and costs thousands of dollars so it requires precise engineering calculations. There are several semi-empirical equations to evaluate productivity index, starting liquid and oil rates, water cut, and other well performance indicators. Despite all of these formulas using understandable mathematical models of fluid flow in a reservoir, they include highly uncertain parameters such as drainage area, permeability, or supply contour radius.

These parameters could be estimated by well test analysis, however, it is expensive and takes dozens of hours to conduct. In our research, we have investigated the machine-learning method in order to reduceing the uncertainty of oil production rate forecast after HF.

The main hypothesis is that a trained regression model based on gradient boosting algorithm is able to predict oil production rate after treatment operations without application of analytical equations. For this purpose, the general workflow was developed and it includes the followings: data preparation, tuning hyperparameters and training of the model, validation on the evaluation data, making forecast based on training data and interpretation of model performance.

As a result, the proposed approach provides time saving in routine reservoir engineering task in conjunction with high-precision oil rate prediction and low uncertainty. Methodology is based on a gradient boosting algorithm and regression problem solving. The latter is related to mathematical method for estimating the relationship between dependent variables and independent variables in order to find the link. The former is key and tool for solving regression problem to find optimal solution.

Gradient boosting is based on decision trees where each branch represents the outcome of regression. There are many techniques such as XGBoost, Random Forest, etc. However, based on the previous experience [3], CatBoost is chosen as the main tool for solving regression problem.

First of all, a machine-learning model has been trained. To receive a good performance of the model and avoid overfitting, the main aspects should be taken into account: applicable loss-function, hyperparameters tuning and cross-validation. Traditionally, RMSE (*Root Mean Square Error*) metric is applied as loss-function (Fig.1) that controls training and quality assessment of regression model [2]