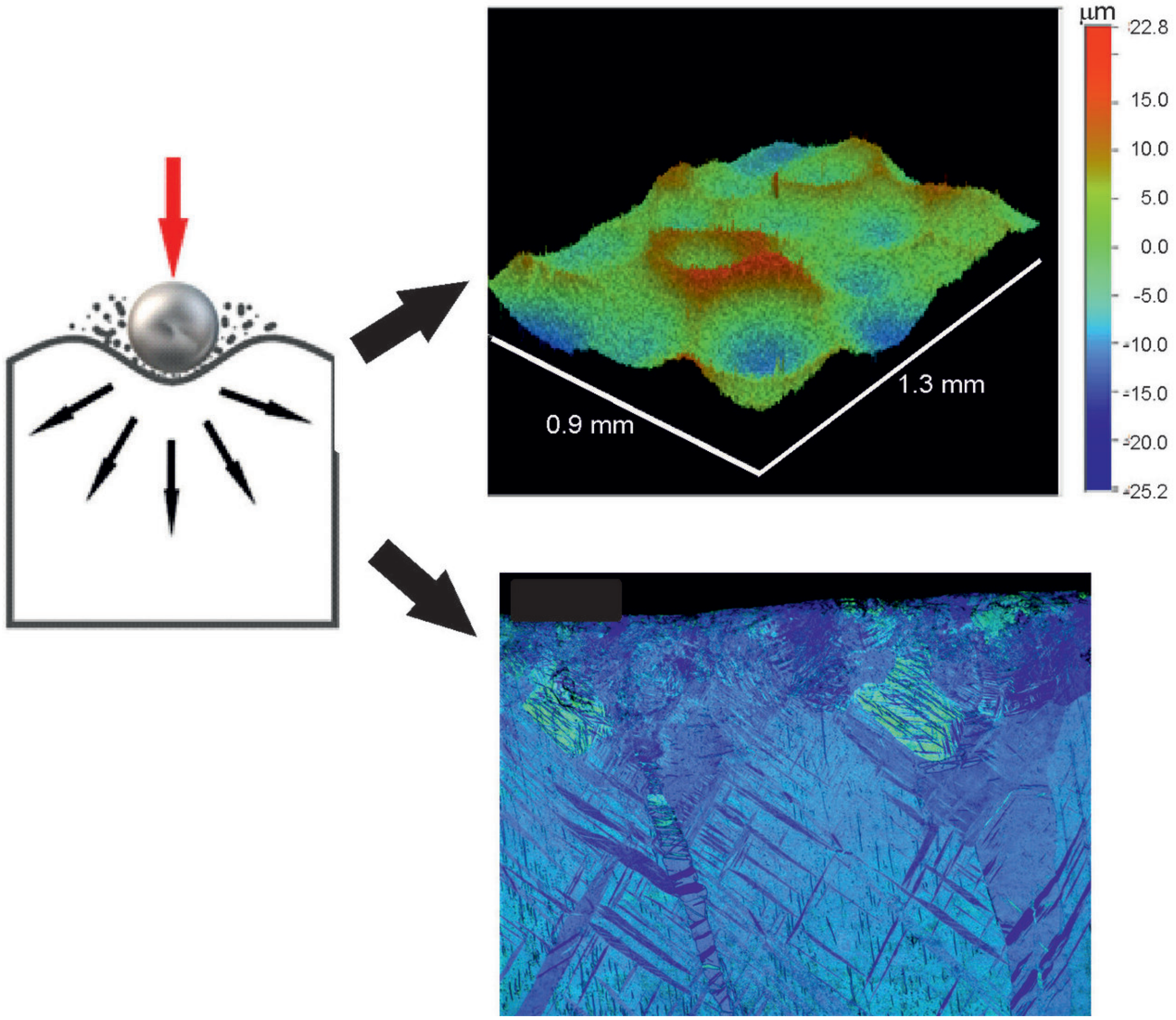
The latest magnesium studies pave the way for new biomedical materials

December 17 2020



Surface mechanical attrition treatment (SMAT) of magnesium improves its strength and corrosion resistance. Credit: IFJ PAN

Materials used in biomedicine must be characterized by controlled biodegradability, sufficient strength and total absence of toxicity to the human body. The search for such materials is, therefore, not a simple task. In this context, scientists have been interested in magnesium for a long time. Recently, using such techniques as positron annihilation spectroscopy, the researchers were able to demonstrate that magnesium subjected to surface mechanical attrition treatment obtains the properties necessary for a biocompatible material.

Materials showing controlled corrosion rate are gaining more and more interest. This applies in particular to biomedicine, where implants made of natural or synthetic polymers are used. Their advantage is that the rate of decomposition can be easily adjusted under physiological conditions. On the other hand, the mechanical properties of these materials are deteriorated in the environment of the human body, making them unsuitable for high-stress applications. For this reason, metallic implants based on magnesium that is entirely harmless to the human body seem to be a good option.

Magnesium is the lightest metal that can be used in structural applications. Due to its mechanical, thermal and electrical properties as well as biodegradability and the controlled rate of corrosion, it sparks great interest in researchers dealing with biocompatible implants. Despite these advantages, the use of magnesium as a biomaterial for the production of implants has not been easy due to the relatively high corrosion rate in the human body environment. However, this problem can be overcome by using appropriate coatings.

In many years of research, it was noticed that the fine-grained microstructure of materials not only improves their mechanical properties but can also significantly increase the corrosion resistance. That is why an international research team led by Prof. Ewa Dryzek from the Institute of Nuclear Physics of the Polish Academy of Sciences in Krakow set the goal of quantifying the impact of the surface mechanical attrition treatment (SMAT) of commercial-grade magnesium on its corrosion resistance. In this method, a large number of stainless steel balls a few millimeters in diameter hit the surface of the target material, causing plastic deformation of the subsurface layer. Plastic deformation is accompanied by the production of a large number of crystal lattice defects.

Typical research techniques such as light and electron microscopy, X-ray diffraction (XRD), electron backscatter diffraction (EBSD), and microhardness measurements were used to describe the microstructure.

"Microscopic examination revealed a gradually changing microstructure of the material's surface layer, formed during SMAT processing. We observed considerable grain refinement close to the treated surface. Deformation twins were visible deeper, the density of which decreased with increasing distance from this surface," explains Prof. Dryzek.

As part of this work, positron annihilation spectroscopy (PAS) was used for the first time. The technique is non-destructive and allows for the identification of lattice defects at the atomic level. It consists in the fact that when positrons are implanted into a material sample and meet their antiparticles, i.e. electrons, they annihilate and turn into photons that can be registered. A positron that finds on its way an open volume defect in the crystal lattice can be trapped in it. This extends the time until it annihilates. Measuring the lifetime of positrons gives researchers a picture of the sample's structure at the atomic level.

The purpose of using this method was, in particular, to obtain information on the distribution of crystal lattice defects in the surface layer resulting from SMAT treatment. Also, it was employed to study a material layer with a thickness of a few micrometers, lying just below the treated surface, and to link the obtained information with corrosion properties. This is important because the lattice defects determine the key properties of the materials as it is utilized, for example, in metallurgy or semiconductor technology.

"The mean lifetime of the positrons in the 200-micrometer layer obtained from the 120-second SMAT treatment shows a high constant value of 244 picoseconds. This means that all positrons emitted from the source reaching this layer annihilate in structure defects, i.e. missing atoms in the sites of the crystal lattice called vacancies, which in this case are associated with dislocations. This layer corresponds to a strongly deformed area with fine grains. Deeper, the mean lifetime of positrons decreases, which indicates a decreasing concentration of defects, reaching at a distance of about 1 millimeter from the surface the value characteristic for well-annealed magnesium with a relatively low density of structural defects, which was our reference material," Ph.D. student Konrad Skowron, the lead author of the article and originator of the studies, describes the details of the work.

The SMAT process significantly influenced the behavior of magnesium samples during electrochemical corrosion tests. Structural changes caused by SMAT increased the susceptibility of magnesium to anodic oxidation, intensifying the formation of a hydroxide film on the surface and consequently leading to better corrosion resistance. This is confirmed by the results obtained with the use of a positron beam at the Joint Institute for Nuclear Research in Dubna, Russia. The results show that besides the grain and subgrain boundaries present on the surface, also other crystal defects such as dislocations and vacancies can play an essential role in the corrosive behavior of magnesium.

"We are currently conducting a similar study for titanium. Titanium is a metal widely used in the aerospace, automotive, energy and chemical industries. It is also applied as a material for the production of biomedical devices and implants. An economically acceptable method that allows obtaining pure titanium with a gradient microstructure with nanometric grains in layers adjacent to the surface may open wider prospects for the use of titanium in products important for the global economy and for improving the comfort of human life," says Prof. Dryzek.

More information: Konrad Skowron et al, Gradient Microstructure Induced by Surface Mechanical Attrition Treatment (SMAT) in Magnesium Studied Using Positron Annihilation Spectroscopy and Complementary Methods, *Materials* (2020). DOI: 10.3390/ma13184002

Provided by The Henryk Niewodniczanski Institute of Nuclear Physics Polish Academy of Sciences

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