Microscopic Analysis of Breakage in Materials for Hard Implants

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***Abstract*— The present paper deals with the analysis of breakage structure and conditions of various composite materials that might be used in the construction of orthopaedic implants. A number of samples were subjected to traction and some others to bending until they reached breaking limit. The structure we obtained after the breaking was analyzed by help of an oral video cam and of a Keyence digital microscope, in order to assess the damages occurred within the internal structure of the material. This will help us find the weak areas and identify possibilities of material's improvement.**

***Index Terms*— breakage, composite material, implants, microscopic analysis**

I. Introduction

Human body is a structure made of 206 bones, interconnected by various types of joints. The skeletal muscles act upon the bones system using its components as levers during lifting weights or performing different motions. This is why the materials used for fracture fixation implants, especially those meant for lower limbs, should be able to resist to considerable forces. The most used materials for orthopaedic implants are metals, usually titanium and its alloys but these present the disadvantage of high stiffness in comparison to the host tissues, depriving them of the mechanical stimulation required during the homeostasis process. Thus, it is necessary to analyze the opportunity of using other types of materials, such as composite materials, in different combinations of layers and also of fibres orientation in order to accomplish a suitable elasticity along several axial directions.

In everyday life, the implants, together with the bones they are supporting, might be subjected to various stress and strains due to common motions like running, jumping or climbing, or due to unexpected accidents leading to impacts and shocks. Considering the fact that most of the implants are in direct contact with the human tissues, it is of utmost importance to analyze what happens at microscopic level inside the material during an extreme strain that might lead to rupture. The way the material breaks provides valuable information related to the weak points, the elasticity and stiffness of the tested sample.

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II. Theoretical Aspects

In composite structures, completely different substances may combine so that their individual properties reach an optimum action. Usually we deal with pairs of materials selected according to the idea that one has a bearing function and the other one assumes the moment of inertia. If a constructive element made of fibre reinforced composite material is subjected to a multi-axial load, there is required to create a fibre disposition along two or more directions. If there are preferential directions of fibres' orientation then there will also be preferential directions of the elastic properties.

Provided we are using a multilayer composite material based on a polymeric matrix, we must take into account the fact that the bending resistance is strongly influenced also by the environmental conditions and by the resistance of each lamina. There are several rupture criteria applicable to fibre reinforced composite materials, some of them using empiric relations, others are experimentally determined.

Microscopic analysis can be both an intermediate control method and a final one. Its importance is given by the fact that the control can be made upon the breakage surface, upon the forming surface and also upon special processed surfaces (honed or corroded). We can emphasize several defects occurred in different stages of processing namely: capacity defects (porosity, cracks), surface defects or depth defects. They may be of different nature, size, shape, relative distribution and may lead to faulty products.

III. Experimental Setup and Results

In order to be able to study the alterations occurred within the composite material during the breakage process we used two devices: an oral videocam and a digital microscope. The samples were subjected to traction and bending and studied in the vicinity of the breakage area.

The Acclaim system is comprised of a camera handpiece with a USB umbilical (embedded USB 2.0 interface control module). The Camera Handpiece is extremely lightweight with a high resolution, high sensitivity, auto-exposure controlled CCD sensor and a high performance lens system illuminated by ultra-bright white LED lamps. The fixed focus lens has a broad depth of field bringing all objects

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measuring between 6 and 50 mm into focus enabling the camera to finely detail a section (see fig.1 and 2).

Fig.1 Oral video cam

Fig.2 Images during analysis

The VHX-500 Keyence microscope provides a depth of field at least 20 times larger than optical microscopes. Thus, the VHX-500 can accurately observe a target (even with a large height difference) that could not be focused on with conventional microscopes. It can be connected to the PC and save the images required for analysis. Magnification is between 500x and 2000x (see fig.3).

Fig.3 Keyence digital microscope connected to PC

We used various types of composite material samples for testing, thus: 5 samples made of 4 layers Roving material with different types of fabric orientation (weft or warp fabric), 10-12 samples of 4 layers Mat-Roving type of material (fig.4). The samples were tested both for traction and bending until they reached the breaking limit, then we analyzed the aspect of rupture using the video camera and also the digital microscope.

Fig.4 Samples subjected to bending

In the following we selected the most spectacular and eloquent examples.

In fig. 5 and 6 we presented sample 2 subjected to traction, the sample is made of 4 layers of MAT-Roving combination and was polymerized for 24 hours before testing. The images show that the fibres are breaking towards the external part of the sample, while the matrix is not very damaged.

Fig.5 Sample 2, magnified 5x

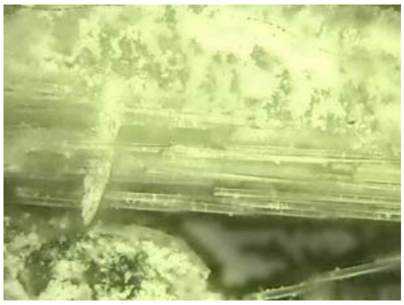

Fig.6 Sample 2, magnified 500x

Sample 5, made of the same material was subjected to bending and the results can be visualised in fig.7 and fig.8. We can see that the fibres broke in a dangerous way, while the microscopic image shows even a significant delaminating of the material.

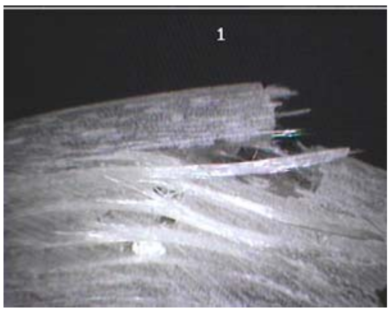

Fig.7 Sample 5, magnified 5x

This phenomenon could be very damaging in case the material is used in the implant construction. On the other hand, we found that the average value of the bending stiffness is around 68000 N/m, which is more than satisfactory for our needs.

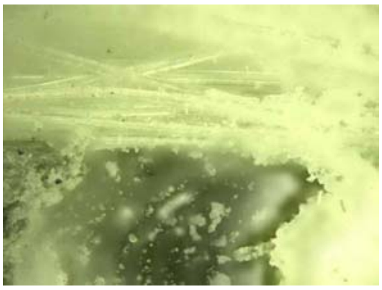

Fig.8 Sample 5, magnified 500x

Some interesting results were obtained by studying different types of fabrics, such as the weft fabric and analyze the behaviour during traction and bending. Thus, in fig.9 and 10 we presented some samples of the material subjected to traction, while in fig.11 and 12, the sample was subjected to bending.

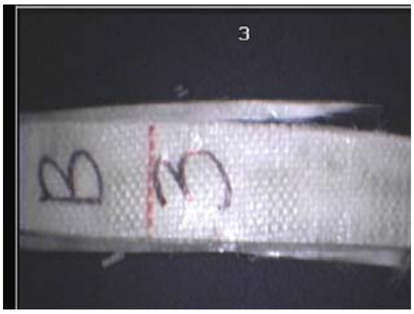

Fig.9 Sample 3, traction, 5x

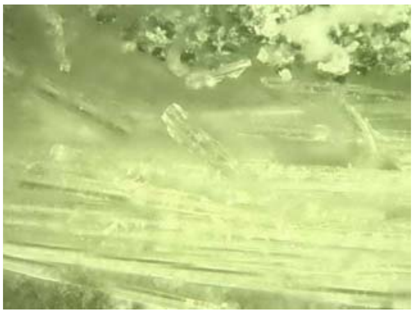

Fig.10 Sample 3, traction 500x

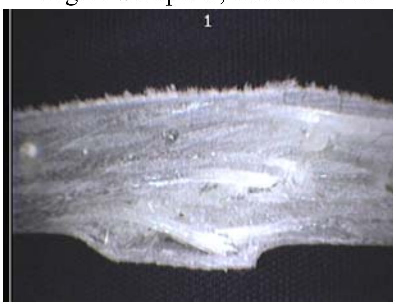

Fig.11 Sample 4, bending, 5x

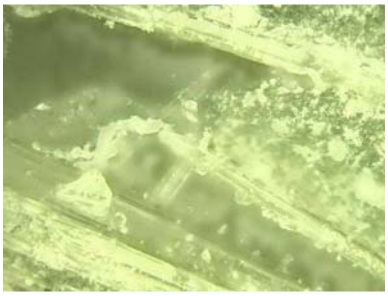

Fig.12 Sample 4, bending 500x

As we can see in the above images, this type of fabric orientation is much more acceptable, as the fibres do not spread significantly after breaking and the matrix structure is only slightly affected.

The next type of fabric we tested was a warp fabric included in the structure of the composite material, again on a multilayer basis. In fig. 13 and 14 we presented the results for samples provided with warp fabric, subjected to bending, as these results provide more important details.

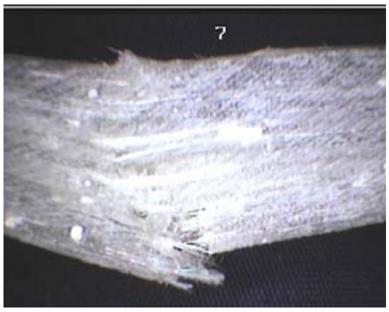

Fig.13 Sample 7, bending, 5x

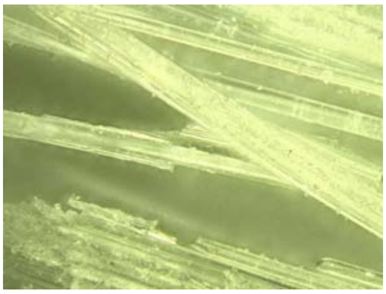

Fig.14 Sample 7, bending, 500x

The images show again a dangerous breaking of the fibres but only for high values of stress, that are not likely to be reached in a regular use of an orthopaedic implant.

IV. CONCLUSIONS

The microscopic analysis of the material provided valuable information concerning the weak elements of the structure and also of the fabric orientation. Obviously the breakage affects both the fibres and the matrix of the material. But it is important to study what happens in case of an accidental breakage of the implant as we have to consider its proximity to human tissues that might be harmed in case of faulty materials.

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After analyzing the studied samples, we found that the best results were obtained for the materials provided with layers of weft fabric. For these samples, the breakage proved to be smoother, the fibres are not chaotically spread and the matrix is only slightly affected. For the other types of samples, the breakage produces more damaging results, the fibres push out of the fabric and we also have a delaminating effect of the matrix. Nevertheless, the values of stress required for the material breaking are improbable to be reached during an accident.

As a conclusion, all the tested materials respond to the requirements of withstanding loads of traction and bending but the material provided with weft fabric layers seems to be much safer.

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