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On the Role of Microscopy in Mechanical Engineering Education

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The paper presents the author's point of view on the role of microscopy in the mechanical engineering education. The argumentation will be supported by the author's experience on implementing microscopy demonstration and training modules in the mechanical engineering undergraduate and graduate curriculum at the Ryan School of Engineering, Youngstown State University (YSU).

The Cambridge Dictionary states that the engineering is the field of study that uses scientific principles to design and build machines and structures at various scales (nano to mega) and for various applications [1]. Microscopy is the science of investigating small objects and structures using a microscope [2]. Based simply on the definition comparison there is a clear overlap between engineering and microscopy.

From the engineering education perspective, the microscopy can be regarded as an educational instrument that can be used in clarifying fundamental engineering concepts. Several examples of microscopy implementation into the Mechanical Engineering Program at YSU are provided below. For the ME sophomores a mandatory course is MECH 2606 Engineering Materials. This is one of the first two specialty courses the ME students are required to take, and it is a challenging one due to the large amount of materials related new concepts the students must learn in this class. For many students it is challenging to understand the concept of polycrystalline materials, as well as the crystallographic imperfections of engineering materials. Textbooks, supplementary information provided by the publishers, and the Internet (including YouTube videos) are good sources of information the students are using. The YSU instructors are using microscopy demonstrations to prove and explain the concept of polycrystalline materials and the crystallographic defects, such as grain and twin boundaries, and dislocations. The students enjoy the opportunity to operate light microscopes and scanning electron microscopes (SEM). Moreover, they learn about sample preparation and metallography, and about chemical composition analysis using the X-ray energy dispersive spectrometer (EDS) in the SEM. The Ryan School of Engineering has a dedicated microscopy facility consisting of a sample preparation laboratory, light microscopes, a variable pressure SEM, and a field emission SEM [3].

Understanding the concepts of polycrystalline material, crystalline grain, and grain size, will also help students to better grasp the concept of strengthening mechanism by grain size reduction, mathematically expressed by Hall-Petch equation.

Another difficult to grasp concept is the slip in single crystals. Visualizing the slip systems in single crystals subjected to tensile stresses is critical in understanding the plastic deformation and strengthening mechanisms of metals. The textbook used at YSU does a good job introducing the geometrical relationships between the tensile axis, slip plane, and slip direction, and in calculating the resolved shear stress [4]. However, grasping the formation of slip line under the effect of the critical resolved shear stress is a difficult task, when looking at the textbook figures. Slip is a dynamic process and the best way to understand it is by live observation. Most of the textbooks, recommend as a laboratory demonstration for slip system formation the use of macroscopic zinc single crystals. An alternative is the usage of sub-millimeter size single crystals loaded in tension in-situ in a SEM. Reichardt *et al*. reported on the in situ micro tensile testing of He^{2+} ion irradiated and implanted single crystal nickel films [5]. Samples with a cross sectional area of approximately 10 μm (width) x 13 μm (thickness) and a gage length of 25-30 μm have been prepared by ion milling in a focused ion beam (FIB) instrument. During the tensile loading process, high definition SEM micrographs were recorded at small strain intervals. In the electronic version of the paper they provided videos of the slip in several Ni single crystals. The videos will not only help students understand the slip mechanism in single crystals, but it will clearly demonstrate the imaging power of a scanning electron microscope in understanding an engineering concept. Moreover, the microscopic tensile testing specimens have been prepared by ion milling. Therefore, the students will also learn about manufacturing using the FIB, which it will be a first for the majority of the undergraduate students.

Table 1. Summary of the engineering concepts taught using the aid of microscopy in three Mechanical Engineering (ME) classes at YSU.

<table>
<tr><th>YSU ME Class</th><th colspan="2">Concept</th><th>Imaging, spectroscopy techniques</th><th>Instrument or related resource</th></tr>
<tr><td rowspan="3">MECH 2606
Engineering Materials</td><td>Polycrystalline, grain size</td><td rowspan="5">Failure/Fractography</td><td rowspan="3">LM
(BF, DF, polarized light and DIC)

SEM
(SE and BSE)</td><td rowspan="2">Nikon SMZ800
Zeiss Axiophot
Olympus BX40
JEOL JSM-IT300LV
JEOL JSM-7600F</td></tr>
<tr><td>Crystal imperfections</td></tr>
<tr><td>Slip</td><td>In-situ SEM [5]</td></tr>
<tr><td rowspan="2">MTEN 5868
Failure Analysis Using the SEM

MECH 6915
Failure Analysis</td><td>Chemical composition</td><td>EDS</td><td>EDAX Octane Plus</td></tr>
<tr><td>Non-destructive investigation</td><td>MicroCT</td><td>General Electric Phoenix V/tome/x S</td></tr>
</table>

Several microscopy techniques are used at YSU to teach the students the concepts of failure analysis, Table 1. At the undergraduate level, besides the introduction of the failure concepts in the MECH 2606 Engineering Materials class, the MTEN 5868 Failure Analysis Using the SEM is offered to the senior mechanical and chemical engineering students. The graduate students have the opportunity to enroll in MECH 6915 Failure Analysis. In both classes the students are trained in sample preparation and operation of both the light and the scanning electron microscopes. Hands-on investigations of fracture surfaces using microscopy help students distinguish between the fractographic features corresponding to brittle, ductile, corrosion, or fatigue failures. At the beginning of the semester, failure analysis projects are assigned to the teams of three to four students. The students are required to use the microscopy instrumentation in their projects and to present their findings in class, at the end of the semester. For some projects, beside light and electron microscopes the micro-computer tomography (microCT) might be used to understand the cause of failure or for non-destructive inspection. Figure 1 shows the results of the microCT investigation performed by YSU students on a 3D printed ceramic and a Cu coated polymer [6].

In conclusion, microscopy is part of the core mechanical engineering undergraduate and graduate education [7].

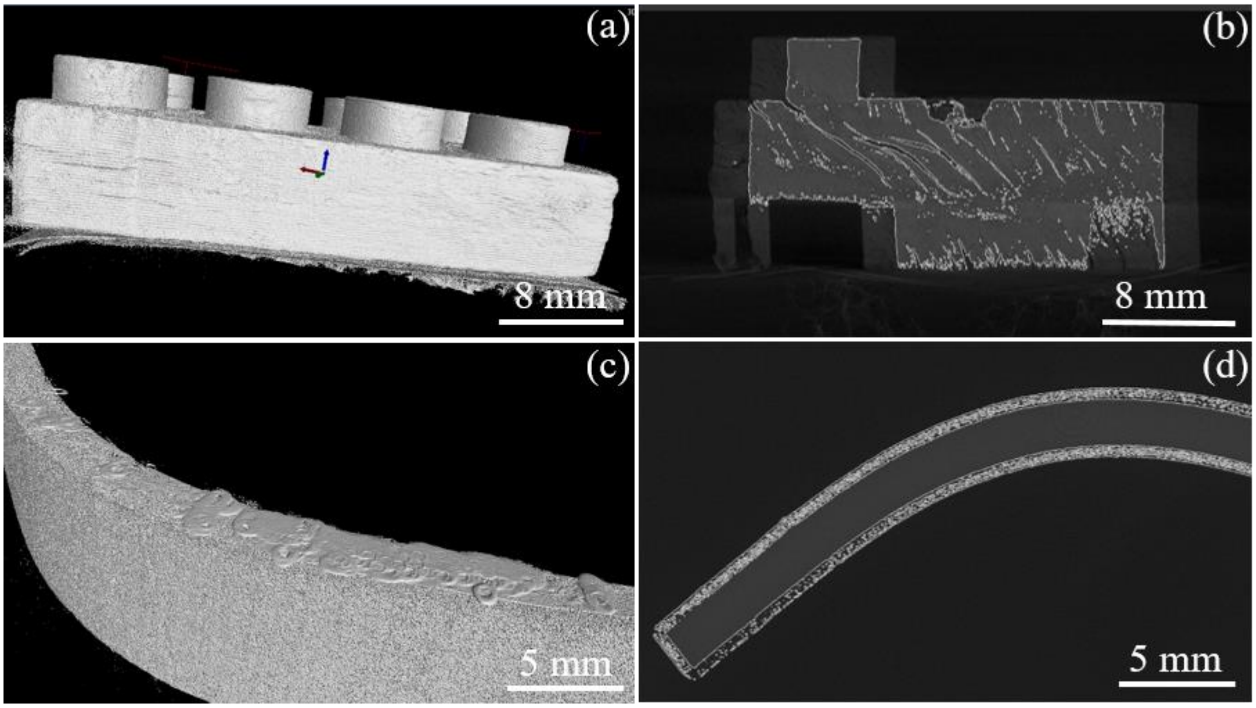

Figure 1. (a), (b) CT micrographs of a 3D printed ceramic. Manufacturing imperfections are visible in (b). (c), (d) CT micrographs of a Cu coated polymer. The uniform thickness of Cu coating can be clearly observed in (d).

References:

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