Integrating Material Science and Processing into the Undergraduate Engineering & Science Curriculum Using the Web

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Abstract

The proper understanding of engineering materials is very foundational and important with respect to all the various branches of engineering, science, and technology for a complete undergraduate engineering program. The purpose of this communication is to help satisfy this requirement for a more thorough undergraduate engineering foundation in a broad range of various courses in the different disciplines across engineering by using the web. This would provide undergraduate students with access to various opportunities and capabilities in their curriculum using the web to access different materials engineering related goals, activities, and learning experiences. The web development work illustrated in this communication will provide undergraduate engineering students a user friendly approach to learning and better understanding the principles of basic fundamental engineering materials, chemical engineering, materials design, engineering science, chemistry and metallurgy necessary for a more fulfilling and exciting undergraduate engineering experience.

Introduction

This project is designed to improve the interactive learning environment that students have in learning material science in their undergraduate studies. Various courses such as metal processing, strength of materials, machine design, fluid mechanics, thermodynamics, manufacturing processes, mechanical behavior of materials, principles of engineering materials, materials laboratory, senior lab, senior design, and metallic corrosion require a good understanding of engineering science and materials for the success of the undergraduate students. The goal would be to enhance and improve the student's materials & engineering science background and knowledge and also their computer skills using the web in an interactive user-friendly environment. Rather than simply reading information from a book, the students would be deeply involved with an interactive instructional learning of materials science, material processing, chemistry and metallurgy. The student would actually be involved in the various experiments and several course tutorials using the web. The proper understanding of manufacturing, metal processing, and engineering materials is very foundational and important with respect to all the various branches of mechanical and manufacturing engineering and science for a complete undergraduate engineering program. The purpose of this proposal is to help satisfy this requirement for a more thorough undergraduate manufacturing and engineering foundation in a broad range of various courses in the different disciplines across engineering by using the web. This would provide undergraduate students with access to various opportunities and capabilities in their curriculum using the web to access different manufacturing processes and metal process engineering related goals, activities, and learning experiences. The major topics to be included include: casting, extrusion, rolling, machining, forging, sheet metal forming, welding, drawing, surface measurement, coating, grinding, and quality control.

Materials Analysis

The student will be able to use the web to simulate the characterization of a given material, metal, or alloy. This would involve performing a given type of materials test, such as tensile or fatigue, using the web, and thus determine the mechanical properties of the material. A user-friendly environment would be active in which the student would be asked a series of questions concerning the type of material characterization of interest. The questions would involve the variables of the type of test, the specific kind of materials, and various other input parameters necessary to perform the type of materials characterization test without having to be actually in the lab. This would help prepare the student ahead of time before actually performing the experiment in real life. The student would learn from his or her mistakes or errors ahead of time rather than having them occur on the material testing machine itself which could be rather costly in term of equipment repairs or even dangerous to the student himself. This would be analogous to a student training in a flight simulator before actually flying in order to better prepare himself for the real life experience. The student would be able to practice a variety of material characterization studies and tests on the web depending both on his particular interests and course requirements. These would include basic tensile and fatigue testing as well as hardness testing, fracture toughness testing, stress rupture testing etc. The ultimate goal would be to compliment, enhance, and add to the student's actual experimental lab experiences in engineering. This would be done in an instructional user environment where the student would learn through the web tutorial.

The web development work would also involve material characterization web development would be that the student could use the web to perform and monitor the actual operation of a piece mechanical testing experiment, such as a mechanical tensile test or fatigue test according to ASTM (American Society for Testing and Materials) standards. For example, a basic mechanical tensile test can be performed and the students can use the web to monitor the performance of the experiment and to obtain data from the tensile testing experiment while it is actually taking place in the lab. A fatigue test may take several days or weeks to run to completion. The student could use the web from his home or a remote location to monitor and evaluate the fatigue test at any time while it is taking place. This would provide an invaluable instructional benefit to the students concerning the actual performance and running of a materials characterization test from start to finish.

Microstructural Analysis

In addition to characterizing the mechanical properties of the material, the students would be able to simulate the microstructure of an alloy. This would be an interactive user friendly approach in which the student would be asked a series of questions concerning the type and processing of the material, metal, or alloy. The students would be asked questions concerning the composition, heat treatments, and manufacturing processing of the material. The student would be able to input variables such as time and temperatures for various heat treating methods such as annealing, solution heat treating, precipitation hardening, etc. The student would also input the various compositions of the major and minor alloying elements. The student would be able to input various manufacturing process variables such as the extrusion or forging temperature, extrusion ratio, billet geometries, etc. Based on the input given by the user, the computer would then generate/simulate the microstructure of the metal or alloy. Thus, the student would go through an instructional tutorial on the microstructural characterization of various metals, alloys, and other materials such as composites or polymers. The student user would also be able to change some of the processing parameters and thus determine what new microstructure or microstructural evolution would occur. This would enable the student to learn about the effects of composition, heat treatments, and processing on the internal structure and consequently the mechanical behavior of the material of interest. Preliminary work has already been started for simulating the microstructures of materials on the computer which would be performed on the web. An example of this is shown in Figures 1 and 2 which are TEM (transmission electron microscopy) microstructures field images, darkfield and brightfield, of an aluminum-lithium-copper alloy that can be easily viewed on the website by the student for a precipitation age hardened aluminum alloys. In addition, the students would be able to access various other microstructures of different exotic materials on the web for various undergraduate course requirements, which might normally be difficult to quickly, obtain.

The microstructure would then be generated or simulated be the student which is asked questions interactively by the computer concerning the composition and heat treatment processing of the given demonstration alloy. The computer then provides the student with various engineering design parameters such as the tensile and yield strength of the alloy, as well as some microstructural design parameters such as the coarsening rate, average particle size, and the precipitate free zone width for the given demonstration material. The student would obtain the output from interactive instructional correspondence with the computer based web environment. The student can obtain important microstructural design information concerning the distribution of the particle sizes in the microstructure and important statistical parameters which describe the particle distribution, such as the coefficients of variance, skewness, and kurtosis, as well as the standard deviation. The undergraduate student can obtain important engineering design parameters such as the yield strength and ultimate tensile strength dependence on the heat treatment (and composition) of the material of interest.
Variations in three different variables (composition, aging time, and heat treating temperature) are represented for the given demonstration alloy. Various other materials and variables can also be studied by the student in the user friendly interactive computer environment. The aluminum-lithium alloy was selected here as the demonstration alloy primarily due to its relevance to the aerospace and aircraft industry for applications involving commercial and military aircraft. The student through the interactive user-friendly web based environment can potentially study any number of interesting materials such as polymers, ceramics, biomaterials, superalloys, composites, or other exotic materials and alloys.

Metallurgical Engineering on the Web via Materials Design

This part of the web development would include the metallurgical and material science aspects of the web work. This would include the various phase diagrams, crystal structures, deformation mechanisms, atomic structures, lattice defects, time-temperature transformation diagrams, theoretical models, and alloying requirements necessary for designing materials and microstructures. For a given alloy or material, the student would be able to go through an interactive learning tutorial on that particular material in terms of its structure, including the atomic structure, microstructure, and grain structure, its composition and alloying, its phase diagrams, its properties, and its processing. With this information, the student will be able design various materials for specific applications in industry, research, and development. Based on given desired mechanical properties of an alloy, the student will be able to design the processing and microstructure necessary to obtain given mechanical properties. This would all be constructed in an instructional format that would teach the students the fundamentals of material engineering design, chemistry of materials, and metallurgy.

Microstructure and Microscopy

This part of the web development would involve the digital imaging microscopy of actual microstructures of materials directly onto the web. The microstructure's image would be directly converted from the optical or electron beam microscope to the web environment. Thus the student would see the actual microstructure of the material as it would be viewed from either a optical microscope, or a scanning electron microscope, SEM, or a transmission electron microscope, TEM. This would enable students who do not have access to optical or electron microscopes to still have the capability of microscopically studying a variety of engineering alloys, composites, polymers, or exotic materials. Microstructural images of materials can be obtained and saved through the optical and SEM and TEM and thus implemented to the web environment for undergraduate students to access. Also special software can be used to convert an optical image into an image on a screen monitor and to the web. The microstructure image on the web can be manipulated for size, resolution, and color for study and printing.

Institutional benefits Gained from the Ongoing Project

The college or university would substantially benefit from the proposed web based project development since the deficiencies in the areas described would be satisfied in a cost effective way. For example, the a materials testing system is very expensive, and having the students get experience on the web and go through a few tutorials will save a lot of time and money. Since the college has one materials testing machine, the time on the machine is limited and the cost of actual material and machine time is extremely expensive. The web-based experimentation and design will be a cost effective way of teaching students the use of expensive equipment in a safe environment. This web based instructional technology helps the college to be competitive in science and engineering, and thus improve the overall quality of undergraduate education. The web development work proposed in this communication will provide undergraduate engineering students a user friendly approach to learning and better understanding the principles of basic manufacturing of fundamental engineering materials, materials design, metal processing, necessary for a more fulfilling and exciting undergraduate engineering experience at the University, College, or technical institution.

The goal would be to enhance and improve the student's manufacturing processes, materials, engineering science background and knowledge and also their computer skills using the web in an interactive user-friendly environment. Rather than simply reading information from a book, the students would be deeply involved with an interactive instructional learning of manufacturing, metal forming, material processing, mechanics, and metallurgy. The student would actually be involved in the various experiments and several course tutorials using the web.

Project Management

The entire Materials Testing System costs several thousands of dollars and having the students get experience on the web and go through a few tutorials will save a lot of time and money. Since we only have one materials testing machine, the time on the machine is limited, and the cost of actual material and machine time is extremely expensive. The web-based experimentation and design will a cost-effective way of teaching students the use of expensive equipment in a safe environment.

A website named "Material Science Lab." has been developed to demonstrate the different research works. This site has different sections which include:

1. Research Works
2. Course Information (Linked to Blackboard 5)
3. Materials
4. Interest

Also it has the link to view the Research Details which states the recent and ongoing research studies.

In the web development work, different sub tasks were completed and are describe as follows:

1. Microstructure (includes Al-Li-Zr peaks, Al-Li-Cu, and picture at different temperatures)
2. Processing (includes Extrusion Geometry, Processing, and Heat Treatments)
3. Deformation (includes Orowan Mechanism, Microvoid growth, Deformation Mechanism, Dislocation-particle shearing Mechanism, Size and Size Distribution effects, etc.
4. Texture (includes Grain Size Hardening in Al-Li Alloys, Grain Orientation Texture Factor M, Equations of Model, and Taylor Texture Factor M for Binary etc.)
5. Fatigue (includes Basic Fatigue Models/Approaches, Basic Fatigue Regimes etc.)
6. Aging Curves (includes Yield Strength vs. Aging Time curve)
7. Particle Size Notes (includes Particle Size, r, Al_3Li Particles Aged for 225 hours, Precipitates in Binary Al-Li, and Al-Li-Cu)
8. Strengthening; includes Comparison Between the Yield Strength and Interparticle Spacing for the AlLiZr, Total Precipitation Strengthening, The Dislocation Line Tension, the individual strengthening mechanisms, etc
9. Microscope Photos of the other materials microstructures including Ti-6Al-4V, Al-Sc-Ti, and steel.

The front or home page has been developed using macromedia software named "Dreamweaver" [1]. To develop other links like research works, research details etc. hypertext marked up language (HTML) of version 4.0 has been used and as well as to view by browsing Microsoft Internet Explorer 5.0 [3]. For the images, those have been attached with the documents, "Adobe Image Ready, version 2.0" [2] has been used to make more optimized and usable to attach into the html files. Almost every image has been resizes approximately 500X600 resolutions depending on the actual image size and then file size is reduced by optimizing option of Adobe Image Ready software. And at end before attaching to the html file, images have been saved as jpeg or gif format. Some documents are first processed by Microsoft Office XP (Microsoft Word) [4] then it has been transferred to HTML format to upload. To scan the images special software named "EPSON Smart Panel"[6] is used which was totally hardware dependent to the EPSON Perfection Scanner of model 1240U.

The interactive webpage that was developed displays the microstructures and results of the work. The webpage was developed as a demonstration tool for illustrating some of the results of the work completed. The website displays various microstructure digital images that were obtained by using the image pro quantitative image analysis software. Thus, the quantitative image analysis of a material's or species internal structure or microstructure is a powerful research tool for microcharacterization for understanding the material or species accurately enough to determine the properties or components. Using the microstructure images determined, the web-based microstructural characterization and analysis tool will be used in courses like science of materials, engineering materials, and mechanical metallurgy.

Summary and Conclusions

In conclusion, the materials web-design can be used to analyze a variety of newly developed engineering materials currently being developed for various industries such as the automotive and aerospace. The web-design could be developed to incorporate new advances in microstructural analysis and materials design. All of this is to be implemented into the college class plan through specific homework assignments and projects. Homework assignments involving microstructural analysis involving the measurements of various microstructural features such as the average grain size, ASTM grain size number, particle size measurements, inclusion size measurements, etc could be performed by the student. The students would first view the microstructures on the internet web environment and then choose the appropriate magnification to make the desired measurements. The students could then use quantitative analysis to perform the measurements of the microstructural variables. The student could then correlate the microstructural variables of the given material to the materials mechanical properties and the manufacturing and thermal processing schedules. The engineering student would also be able to modify the chemistry and processing to adjust the microstructure of the alloy and thus improve the mechanical properties. All of these procedures could easily be included into a engineering material science course or a course in mechanical metallurgy for the students to use to help them better learn about materials and the science of engineering materials.

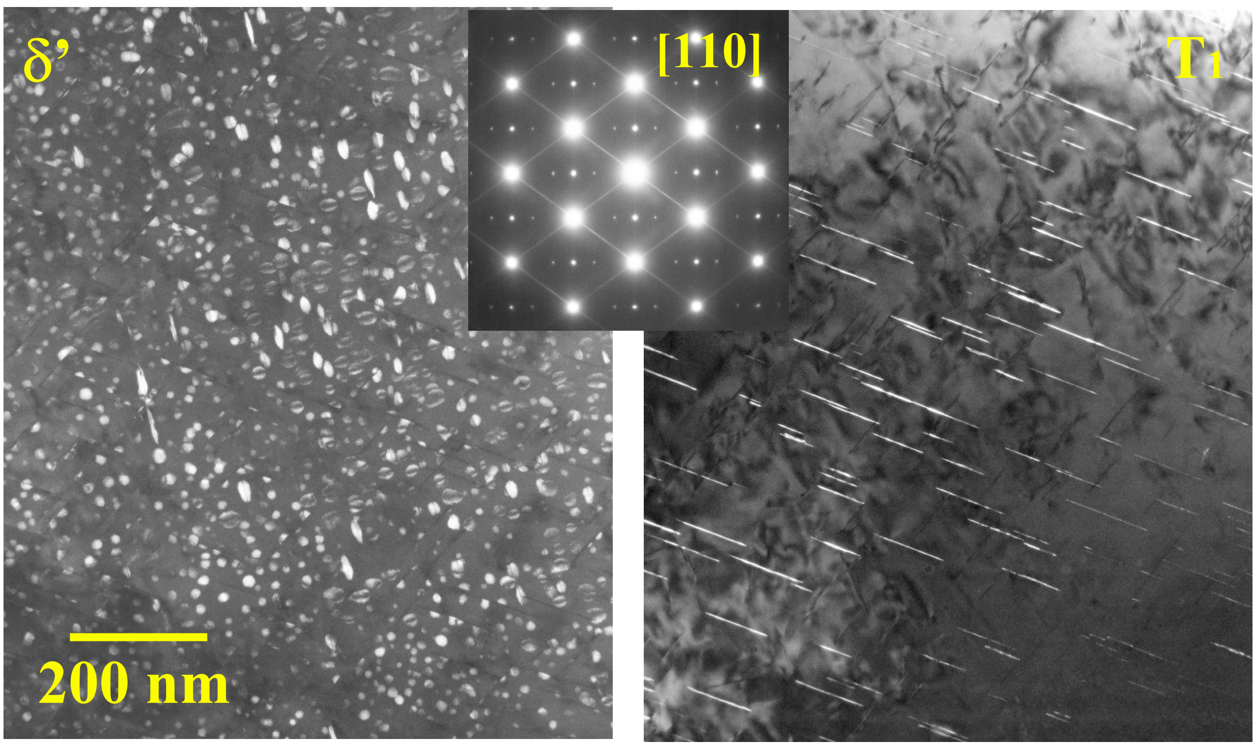

Figure 1. TEM Microstructures of a Precipitation Age Hardened Al-Li-Cu Alloy showing darkfield images of the Al_3Li (δ’) and Al_2LiCu (T_1) Precipitates microstructures aged for 24 hours at 150 ^oC.

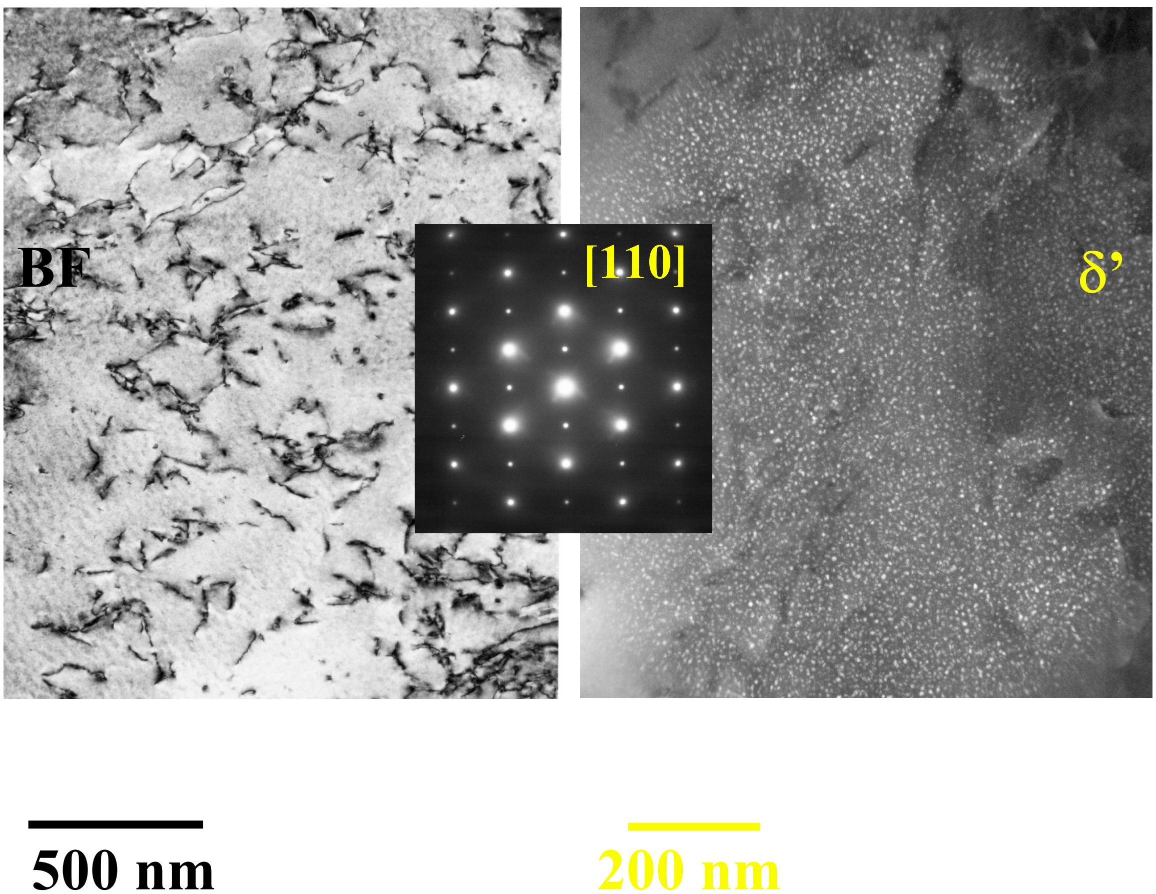

Figure 2: TEM Microstructures of a Precipitation Age Hardened Al-Li-Cu Alloy showing brightfield image of the dislocation structure and a darkfield image of the Al_3Li (δ')Precipitates in the microstructures aged for 3 hours at 150 ^{o}C.

References

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6. EPSON Smart Panel for scanner (Windows: V1.02 Macintosh: V1.03)

Biography

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