The Design of *Material World*, an Internet-Based Educational Environment

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1.   ABSTRACT

Engineers need a solid understanding of the relationships between material processing, properties and structures to make informed material selection decisions for design applications. Hands-on laboratories help students develop this understanding. However, time constraints, equipment costs and safety concerns severely limit the amount of true experimentation that is performed. A bold initiative is underway at the University of South Carolina to develop *Material World*, an expandable internet-based virtual environment where students make, break and look at metals, polymers, composites and ceramics. *Material World* will be based on realistic interactive animations, but includes video clips, sound, photographs and text. In it, students will be able to set processing and testing equipment operating conditions in almost any way they want.

Material World will be a powerful complement to lectures and real-time laboratory courses. Assignments in the *Material World* will be open-ended, such as to make materials with some optimum property or set of performance characteristics. By letting students determine for themselves how processing conditions affect material behavior, *Material World* will enable them to use scientific inquiry as an integral part of the learning process. This paper describes the concept, technological hurdles, and implementation plan for *Material World* within the context of other state-of-the-art courseware being delivered on the Internet.

2.   INTRODUCTION
2.1.   Laboratory Experiences

Virtually all U.S. degree programs in Mechanical Engineering include a course on Engineering Materials. These courses often include hands-on laboratory experiments (e.g., the University of South Carolina's EMCH 371). There is no substitute for the knowledge students can gain by physically touching the materials and using the equipment. However, time constraints severely limit the amount of true experimentation that students can perform in EMCH 371 and most other traditional, real-time, laboratory courses. For example, in a precipitation hardening experiment, students may be given samples of a particular alloy and a predetermined heat treatment procedure so that they can get "good" results during the 2-3 hour laboratory period. There is simply not enough time for students to play the "what would happen if I did this" game and really explore processing-property relationships. Another problem with hands-on experiments relates to equipment costs and safety concerns which may reduce some experiment sessions to little more than ten students in a room watching the back of an instructor as the experiment is performed. In large service-type courses and distance education courses, there is usually no laboratory component at all.

2.2.   Multi-Media Courseware and the World Wide Web

The World Wide Web is a powerful tool for educators. A recent survey (1) reported that for 50% of internet users in the US and Europe, the primary use of the web was for education. Although students and teachers must usually search the web themselves to find sites appropriate for their educational objectives, several compilations are available (2-7). We have searched these and other sites to assess the state-of-art in the delivery of educational materials through the internet. The major use of the web is for distributing course syllabi, notes, assignments and solutions. Although a number of web sites do this quite well (e.g. 8-15), they simply broadcast information and do not actively involve the students.

The web is also used for on-line hypertext courseware (16-30) and for disseminating executable courseware through various file transfer protocols (30-41). A number of commercially produced hypertext products for teaching Materials Engineering concepts are also available on CD-ROM or floppy disk (42-46). Hypertext courseware allows students to explore information in almost any order and generally includes color pictures, videos and animations. These have significant advantages over hard-bound textbooks. However, the students can not pursue a thought they might have about the subject material and ask a "what if" type of question. Interactivity has generally been limited to the programmed responses of the software such as answers to multiple choice and true/false test questions.

To provide greater student involvement, projects are underway to allow individuals to remotely operate actual equipment (47-49) and perform simulated experiments through a web browser (50-59). From these web sites, students perform laboratory work and are actively involved in the learning and discovery process. For example, with the "virtual piston" at Rensselaer Polytechnic Institute (50), students change operating conditions, watch reactions and examine readouts of concentrations, pressure, etc. Although excellent uses of internet technology, these labs require significant infrastructure and computational power at the host server location. Also, because the simulation software and/or hardware resides at the host location, these labs can not be easily expanded or modified by other faculty who would like to adapt them for their own courses. Only individuals at the host location can update the information delivered to the students.

3.   THE VISION

The *Material World* will be an expandable internet-based educational environment where students make, break and look at metals, polymers, composites and ceramics. The *Material World* consists of 2- and 3-dimensional interactive animations, video clips, sound, photographs and text. Laboratory assignments in the *Material World* will be open-ended and can be completed by individuals or by student teams. Assignment objectives are to make materials with some optimum property or set of performance characteristics. For team projects, members will perform individual experiments within the virtual environment, and share data and work on a collaborative report by way of the internet.

Students will enter *Material World* from a single starting-point web site. The site will explain how *Material World* works, offer suggested laboratory assignments and provide links to virtual materials and to virtual processing and characterization equipment. Examples of places the students could go are shown in Table 1.

Table 1. Potential *Material World* Laboratory and Manufacturing Sites

The Sample Preparation Room	The Heat Treatment Shop
The Tension/Compression Lab	The Plastic Compounder
The Creep Test Lab	The Injection Molding Plant
The Microscopy Center	The Glass Shop
The Examination Room	The Cement Mixer
The Foundry	The Prepreg Plant
The Rolling Mill	The Lay-up and Autoclave Shop

Each test lab and manufacturing facility will contain a realistic representation of the equipment and material. Students will operate the equipment with a control panel window at the side of the computer screen. They will choose the operating conditions, perform the task and save results by copying graphical and numerical results from an output window on their computer screen to their personal electronic Lab Notebook. The labs and manufacturing facilities will also contain links to hypertext web pages, so the students can learn the appropriate theory "just-in-time." Since the modules are to be run on internet-compatible computers, the students can also use email to contact a real instructor for more information. After the experiment is completed, the students will analyze their results off-line and prepare a report in a format to be determined by their course instructor. The students will also self-test their knowledge in "The Examination Room" which is a series of multiple choice and true/false questions.

Material World will be a tremendous complement to traditional materials laboratories. Students will be in control of the material's composition and can process it in almost any way they want. If they make a mistake and melt their virtual metal in the virtual heat treating furnace, the virtual furnace may be damaged or the virtual student may be hurt but the real student can start over immediately. Another plus of the *Material World* will be a time-warp feature that eliminates the boredom associated, for example, with waiting for a metal to age or for a composite to cure.

4.   THE DEVELOPMENT PLAN
4.1.   Technical Details
User-friendliness is the first major design requirement for *Material World*. Thus, the user interface will be a graphical point-and-click type. The second major design requirement is that *Material World* cannot be static but can be continually expanded and updated by anyone with an interest in doing so, be that interest either personal or financial. As such, the *Material World* environment is be designed around three basic components:

      (a) tagged data file modules that contain the constitutive behavior of the material;
      (b) web browser plug-in programs for navigating Material World and for performing virtual processes and tests; and
      (c) html hyper-text documents containing procedures, theory and virtual tours.

Data File Modules. All of the information that characterizes a material's behavior during processing and testing will be contained in a materials data file module. This includes constitutive equations, values of the parameters in the constitutive equations, URL addresses for microstructural images and special parameters that record the processing history of the material.

The materials' descriptive information will be obtained from the investigator's experience and from open literature sources such as the ASM Handbook, textbooks and journal articles. The data will be digitized from graphs and tables, rather than reproduced directly. Copyright approval will be obtained as needed.

Each material module will be identified by a code to tell the other computer programs what information is in the file and how it is used. These modules will be coded according to a common standard that will be developed though this project with the help of a National Visiting Committee. Since the standard needs to be expandable and flexible, it will be formatted with tags. This is similar to the way TIF images are structured which allows for them to be transferred to different platforms and programs.

Master Plug-In. Navigation, testing and processing will be performed with internet plug-in programs that interact with the user with the material data file modules and with the internet. Plug-ins are virtually platform independent, downloaded programs that run on the user's computer though a typical Web browser. Plug-ins can be written is a variety of different languages; Java and Visual Basic are to be used for this project. Plug-ins are chosen over CGI programs and other host-site server routines because they utilize the user's CPU processing power. The host-site will simply download the plug-in to the user, rather than perform the necessary calculations and push the video and animation files. This is important because it will minimize the amount of traffic on the internet. Also, the user does not need to return to the host site to use a plug-in. This will help avoid the frustration that would occur if a student tried to rerun an experiment when the host-site server was busy or down. To maintain the security of the student's computer, a plug-in registration procedure will be implemented. The integrity of the plug-in and the identity of the author will be verified before the plug-in is added to *Material World*.

Processing and Testing Plug-Ins. After the student launches a processing or testing plug-in, they then input the experimental conditions. For example in the case of a Rockwell Hardness test, the students will select the applied load and type of indentor. They would be responsible for selecting the appropriate combination to give a valid result. When the simulation is started, the student will see a 2- or 3-D computer animation or digitized video segment. Animations are preferred because they can be changed by the plug-in based on the user's input experimental conditions. For example in the case of a virtual rolling mill, the spacing between the rollers that appear on the user's computer screen will reflect the reduction in thickness they specify. Each plug-in will find the information it needs by reading the tags in the material data file module. Each plug-in will also create output. In the case of a processing plug-in, the output is a modified material data file module. For testing modules, the output is the appropriate combination of graphical and numerical results.

The plug-in programs will be robust. For example, if a user tries to process a material using a process that is inappropriate, they will be informed of that fact. However, the system will allow the user to proceed if they chose to, and will be capable of simulating catastrophic results such as material melting or equipment failure. Users can reprocess, retest or dispose of material at any time. If the user chooses to dispose of the material, then the material file will be deleted from the

user's machine. There could even be process simulation plug-in modules for materials which require special handling procedures for disposal.

Hypertext Documents. The capabilities of html hypertext documents were described in section 2.2 of this paper. Existing educational and commercial web sites are to be utilized to the extent possible. Hypertext documents will be used to provide background information to the user for every material, process facility and test lab in *Material World*. For example, the process facility simulations could include links to a "virtual plant trip" of an actual manufacturing facility. These will link the lab work to reality, and will help show the students what they'll be doing upon graduation and throughout their professional career. This provides motivation for them to continue working, thereby positively affecting engineering student retention rates. Hypertext with CGI forms may also be used to create the student self-testing sections in the "Examining Room."

4.2.   Specific Lessons

Material World will use the strength of the internet to gather knowledge from experts world wide to facilitate student learning of basic material behavior concepts and processing-structure-property relationships. The first components of the *Material World* system that are under development are a titanium material module, a cold-rolling plug-in, an annealing furnace plug-in, and a Rockwell hardness testing plug-in. The technical content for these modules can be taken from work by Conrad et al (60) on the hardness and microstructure of nominally pure titanium in the cold-worked and recrystallized conditions (see Figure 2a). Analysis of their results indicates that the relation between the Vickers Hardness the initial amount of cold work is described reasonable well by a 2nd-order polynomial. The prototype data module for titanium will include tagged sections containing this equation, variables for the initial and current thickness of the plate (initially equal) and a variable representing the amount of cold work, CW (initially zero). Other tags will be added to the data file as *Material World* expands to include other processes and tests.
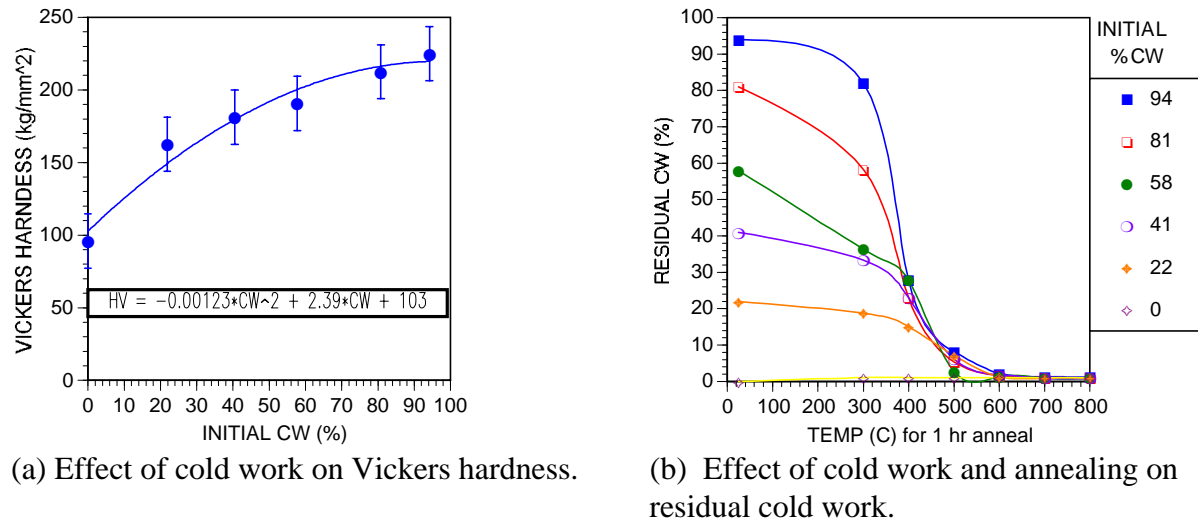

(a) Effect of cold work on Vickers hardness.   (b) Effect of cold work and annealing on residual cold work.

Figure 2. Literature results (ref. 60) analyzed for titanium rolling and annealing simulations.

When the student launches the cold rolling plug-in, they will see a simulated rolling mill and a control panel on their computer screen. Through the control panel, they will set the rolled thickness of the product, then perform the simulation. The plug-in will calculate the amount of cold work put into the titanium and add this amount to the residual CW variable in the material file. This is repeated each time the cold rolling process simulation is performed.

When the student takes the titanium into the Rockwell hardness test plug-in, they will see a simulated hardness tester and an array of simulated weights and indentors. They will install the weights and indentors by clicking on each and dragging it to the appropriate location on the hardness tester. In sequence, they press buttons for "apply minor load", "apply major load", and "remove major load" to perform the simulation. During this time, the plug-in converts the HV value of the metal to the Rockwell scale that the student selected, and the simulated dial of the hardness tester rotates appropriately. The student must read the dial correctly to determine the hardness number.

The student might next put their titanium into the virtual annealing furnace. Again, from an analysis of Conrad's results, it is possible to estimate the amount of residual cold work after one-hour of annealing at different temperatures, as shown in Figure 2b. After the student sets the temperature of the virtual furnace, it begins to glow appropriately. A time-lapse clock sounds an alarm after "1 hour", and the furnace turns off. Using a response surface to represent the data in Figure 2b, the plug-in will calculate the new amount of residual cold work in the sample from the old CW variable in the titanium data file and the specified annealing temperature. Then, the CW variable in the data file is updated. The student could then retest or reprocess the titanium at their discretion.

It is noted that simple empirical analyses of experimental results such as described above can only give approximations to the true constitutive behavior of a material. As described, expansion of this module to include other annealing times requires additional experimental data. Also, since metallurgical changes other than recovery, recrystallization and grain growth could occur in a real annealing heat treatment, errors in the predicted hardness values could increase as the material is reprocessed repeatedly. However, *Material World* is not intended to be an expert system of unified, micromechanics-based constitutive laws (although these will be used when practical). Rather, the objective is to create a learning environment for students to obtain an understanding of fundamental processing-property relationships. Since it is experientially based, the students do not need significant background, preparation or experience to use *Material World*. They will learn by discovery. This will make *Material World* a powerful educational tool.

5.   Conlcusion

The *Material World* exercises will be a tremendously powerful complement to the hands-on laboratory sessions. Students will be able to do more than follow cookbook laboratory procedures using pre-processed samples. They will be able to set processing and testing equipment operating conditions in almost any way they want. By letting the students determine for themselves how processing conditions affect material behavior, *Material World* will enable them to use scientific inquiry as an integral part of the learning process. We have chosen to

develop this environment using internet technologies to effect the largest possible national impact

6.   Acknowledgement

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