Laboratory Experiments and Teaching Methodologies for Learning Dental Materials

K.V. SUDHAKAR
Department of Mechanical Engineering, Universidad de las Americas-Puebla,
Santa Catarina Martir, Puebla 72820, Mexico
Email: sudhakar_vadiraja@yahoo.com

ABSTRACT

This paper discusses some of the specific teaching methods and supplemental experimental methodologies for learning dental materials. Teaching tools discussed in this paper include; competency based curriculum, discussion based model approach, and lecture quiz approach. This course is basically a combination of developed and redesigned course on dental materials for which the course objectives, course methodologies and learning objectives are also discussed. The specific experimental procedures for carrying out the mechanical tests and microstructure analysis are introduced. The basic objective of these experiments is to give students the hands-on experience. More importantly, considerable emphasis is given for improving students' learning skills and creative thinking by having small group discussions and frequent quizzes on laboratory exercises. The direct benefits of experimental exercises to materials science/mechanical engineering education have been discussed.

INTRODUCTION

The purpose of this elective course is to nurture scientific/engineering interest on such important materials and also fulfill industrial needs in that direction. This paper discusses some of the laboratory experimental methods for enhancing student's skills to evaluate mechanical properties and microstructure of dental materials. The typical undergraduate mechanical engineering curriculum has a basic course in materials science that deals with topics like atomic bonding/structure, heat treatment, mechanical testing, and microstructure analysis in various materials viz., metals and alloys, polymers, ceramics, composites and others. However, there is an important need for mechanical engineering undergraduates to study one of the most important advanced materials like dental materials. The proper understanding of mechanical properties and microstructure of dental materials is very foundational and also beneficial for designing dental materials. The literature reviews[1-5] dealing with various important types of dental materials and their mechanical properties are very useful for learning dental materials.

One of the popular teaching methods used for dental materials is a problem-based learning (PBL) that is a continuum of approaches rather than one immutable process.[6,7] It is a teaching method that can be included in the teacher's tool-kit along with other teaching methods rather than used as the sole educational strategy. PBL reverses the traditional approach to teaching and learning. It starts with individual examples or problem scenarios which stimulate student learning. Based on this method, students arrive at general principles and concepts which they then generalize to other situations. PBL helps in curriculum planning by defining core, ensuring relevance of content, integrating student learning and providing prototype cases. There are also drawbacks associated with PBL like students may fail to develop an organized framework for their knowledge. The PBL process may inhibit good teachers sharing their enthusiasm for their topic with students and student identification with good teachers. The problem scenario is of crucial significance. It should engage the students' interest and be skillfully written. The clinical tasks carried out by the strident may replace the problem scenario as the focus for learning. Students are supported during the PBL process by tutors and/or study guides. The amount of support required is inversely, related to the students' prior learning and understanding of the PBL process. A range of additional learning resources and opportunities may be made available to the students, including textbooks, videotapes, computer-based material, and lectures. Tutors require group facilitation skills, an understanding of the PBL process and knowledge of the course and of the curriculum in general. Curriculum design involves a skilful blend of educational strategies designed to help students achieve the curriculum outcomes.[8]

William A Brantley and Theodore Eliades[9] have discussed various technical aspects of dental materials in their new text book. This new textbook deals with the details of all scientific and clinical aspects of orthodontic materials. Recent developments in science and technology have led to the introduction of a plethora of new orthodontic products. This work serves as an excellent source of information for a field that requires knowledge of basic elements of materials science, engineering, chemistry, and physics, as well as clinical orthodontics. The subject has been part of undergraduate/graduate orthodontic education for almost three decades. Besides servicing the orthodontic training programs, the book also investigates the interactions of orthodontic materials with other dental materials as well as hard tissues in the oral cavity. This gives a background to allow for proper material selection for efficient orthodontic mechanics.

Rock et.al[10] have surveyed current orthodontic teaching practice in the undergraduate syllabus at British dental schools and tested the abilities of undergraduate students according to the requirements of the General Dental Council (GDC) regulations. Information collected by means of a questionnaire sent to each dental school in 1998 was compared with similar data from 1994. The orthodontic knowledge and treatment planning ability of students was assessed by a multiple-choice examination paper completed by a random 10% sample of students from each dental school. In 1998 on average 195 curriculum hours were devoted to orthodontics and each student treated five patients. The teaching of fixed appliances had increased considerably between 1994 and 1998. Students scored well on questions that tested basic knowledge but much less well when they were required to apply that knowledge. Only three schools felt that it was realistic to expect undergraduates to formulate orthodontic treatment plans, as they are required to do by the GDC. Results support the view that undergraduate orthodontic training should concentrate on diagnosis and recognition of problems rather than on providing limited exposure to treatment techniques.

Schweitzer and Cohen[11] introduced instruction on dental materials focusing on the individual needs of students, ensuring that students with lower scholastic aptitudes obtain the skills and knowledge necessary to function successfully as professionals. This study determined the effects of the personalized system of instruction (PSI) on end-of-course achievement, aptitude-achievement relationships, long-term retention, and course attitudes. The PSI method of instruction was compared to a conventional lecture/laboratory approach for teaching a dental materials course to dental hygiene students. Although there was no significant difference between conventionally taught and PSI students on the end-of-term final examination, lower aptitude students in the PSI class scored significantly higher on the final examination than lower aptitude students in the conventional class. Of students completing a one-year retention examination, those in the PSI class scored significantly higher than students in the conventionally taught class. Student course ratings favored PSI instruction both at the end of the course and at the one-year follow-up interval.

CLASS-ROOM TEACHING TOOLS

The following class-room teaching methodologies are evolved as a result of new development as well as the redesign of the undergraduate course on dental materials.

COMPETENCY-BASED CURRICULUM FOR DENTAL MATERIALS

Since dental materials are one of the advanced materials of great importance in this millennium for varieties of strategic applications, it is but natural for us to include a competency-based academic curriculum for it. One of the basic components of competency based curriculum on dental materials is to focus on the following aspects of teaching and learning:

Teaching

- Nurture curiosity, creativity, critical thinking and enterprise.
- Remain relevant to the demands of a rapidly transforming society.

Learning

- Merge academic rigor with the thrill of discovery.
- Stimulate minds and encourage cross-disciplinary discourse.

The success of this competency-based curriculum requires application of different educational strategies.[12-14]

The first step in a competency-based curriculum is the development of a set of competency statements to define what knowledge, skills and attitudes the mechanical /materials engineering undergraduate should possess. This set of competency statements will then provide a standard for identifying the core content of the curriculum and allowing the assessment of outcomes of the curriculum. Competencies in the curriculum should be reviewed and modified to be responsive and reflective of the educational needs of the students, community demands and changes in professional practices.

UNDERGRADUATE COURSES ON DENTAL MATERIALS

Typical components of an undergraduate course on dental materials include; course objectives, learning objectives and course methodology as described below.

COURSE OBJECTIVES

Material selection is a challenging task in developing a medical device. Many factors that are often competing need to be considered for making decisions, including mechanical properties, biocompatibility, production costs, and microstructure. This course familiarizes the student with relevant material issues and highlights the process for matching material performance with the design of a particular machinery/device/equipment. The students' knowledge of dental materials will be increased and an appreciation for the relationships between a material's structure, its properties, and the implementation of properties to achieve a desired functionality will be developed.

LEARNING OBJECTIVES

Upon successful completion of this course, the student will be able to:

- Identify the strengths of a given class of materials regarding their use as dental materials.
- Identify the weaknesses of a given class of materials regarding their use as dental materials.
- Select a candidate smart material for a given orthodontic application.
- Factor the strengths and weaknesses of a dental material into the design of a product in orthodontic application.

COURSE METHODOLOGY

The instruction for this course is of an interactive lecture style format. The first half of the semester concentrates on basic mechanical testing and on the properties of different classes of materials. The second half of the semester focuses on principles, methods of metallographic examination of dental materials. The course descriptions are given in the Appendix.

DISCUSSION MODEL APPROACH IN TEACHING DENTAL MATERIALS

A discussion model is used to understand and interpret the topic "Mechanical testing and microstructure analysis" procedures for dental materials. This model aims to make small-group discussion more meaningful and effective in light of limited spatial resources and growing class sizes. Typical class size is 15. The course structure involved 3-hr class discussions that compliment 3 hr weekly lectures. During each session, the 15 students' discussion group is divided into subgroups of 5 students; each sub-group is given 1 or 2 topics (under which specific problems are highlighted) to discuss. After about 15 minutes of preparation, the sub-groups are encouraged to debate/discuss the issues with each other; the professor acts as a discussion facilitator and summarizes key issues raised during the 3-hr discussion. Each group selects a recorder who will then summarize and present key issues. This will enhance communication skills and develop students' ability to make convincing arguments in a very short time period. The recorder can be rotated among each group members. Another more important consequence is that the teaching method should shift in emphasis from passive lecturing to mentoring and small group tutorials. Small group tutorials would also enable students to participate more actively in group discussions and further develop their listening and speaking skills.

LECTURE QUIZ APPROACH

The class-room lectures on dental materials include several lecture quizzes as a continual assessment component. Typically, 15-20 short questions (demanding specific answers) in the form of multiple-choice, true/false or computation are asked in each lecture quiz. Students are allowed to discuss the questions and hand in the answers in small groups. The main aim of the lecture quiz is to let the lecturer have a better gauge of whether the students have grasped the main concept taught in each lecture on specialty topics relating mechanical properties and microstructure of dental materials. It also promotes cooperative learning among the students as well as allows them to relate to and reflect instantly on what they have just learned.

LABORATORY EXPERIMENTAL METHODS FOR LEARNING DENTAL MATERIALS

Laboratory experiments are practiced as useful tools to enhance the learning on dental materials.

Educational Contribution of Experiments

Some of the laboratory experimental methods for learning more about dental materials are practiced as additional tools to evaluate their mechanical properties and microstructure. Laboratory experiments are designed and conducted to learn about the mechanical properties and microstructure. Instructional lectures on each experimental method (in a group of maximum 5 students) are given during each group's laboratory classes. Each group has one laboratory class of 3 hrs duration per week. The ultimate goal of these practical exercises is to provide hands-on experience for students in understanding and analyzing mechanical properties and microstructures in dental materials.

TENSILE TEST

Three tensile tests are carried out by each group of students. The tensile tests of orthodontic wires are performed using a microprocessor controlled machine using a load frame of 1000 N capacity. The tests are carried out as per ASTM standard E8. Standard pulley-fixtures are used for tensile testing thin dental metallic wires. The load–displacement curve is obtained to evaluate various tensile parameters.

THREE-POINT BEND TEST FOR FLEXURAL STRENGTH

Three flexural strength tests are carried out by each group of students. Three-point bend test is carried out using an Instron-UTM at a displacement rate of 0.05 mm/min. Specific fixtures are designed and fabricated to suit the size of orthodontic wires. Flexural strength is the measure of how well a material resists bending, or what is the stiffness of the material. Unlike tensile loading, in flexural testing all force is applied in one direction. A simple, freely supported beam is loaded at mid-span thereby producing three-point loading.

In the present case, a rectangular sample having a rectangular cross section is bent until fracture. At the point of loading, the top surface of the specimen is placed in a state of compression, whereas the bottom surface is in tension. Stress is computed from specimen thickness, the bending moment, and the moment of inertia of the cross section. The maximum tensile stress (as determined using these expressions) exists at the bottom specimen surface directly below the point of load application. The stress at fracture using this flexure test is known as the flexural strength, modulus of rupture, fracture strength, or the bend strength. For a rectangular cross section, the fracture stress σ_{fs} is equal to

$$\sigma_{fs} = 3F_f L/2bd^2 \text{ where}$$

F_f is the load at fracture; L is the distance between support points, b the specimen width, and d the specimen thickness/depth. It is important to note that σ_{fs} depends on specimen size. With increasing specimen volume (under stress) there is an increase in flow severity and, consequently, a decrease in flexural strength. In flexural test, since during loading, a specimen is subjected to both compressive and tensile stresses, the magnitude of its flexural strength is greater than the tensile fracture strength.

MICROHARDNESS (KNOOP) TEST PROCEDURE

Ten microhardness measurements are carried out by each group of students. In the present case, testing is considered to be light force since the size of indentations (diagonal length) was less than 20 µm. Thus, hardness numbers obtained from indentations with diagonals measuring less than 20 µm are much more sensitive to variations of a few tenths of a micrometer in the actual or measured length of the diagonals than hardness numbers obtained by measuring larger indentations. Ni-Ti metal wire, because of its very small size required mounting. Sufficient care is taken to ensure that the specimens were well supported in the mounting material. Also, the surface to be tested is placed into the test instrument such that it is normal to both the loading and optical axis. The optical quality of the microscope is such that highly corrected objectives with numerical apertures of 0.9 and greater are used. In addition, dark field illumination and differential interference contrast is used to improve the contrast of the image. This also helps to enhance the user’s ability to detect the ends of the indentations.

Knoop hardness test is carried out on a SHIMADZU Knoop microhardness testing machine (model: 2000-seies). The Knoop microhardness test is used particularly for very thin layers. The long diagonal is seven times, as long as the short diagonal. With this indenter shape, elastic recovery can be held to a minimum. The Knoop test is conducted in the same manner, and with the same tester, as the Vickers test. However, only the long diagonal is measured, except for the projected area hardness (PAH) test. The Knoop hardness is calculated from:

$$HK = 14.2L/d^2$$

Where the load L is in kgf and the long diagonal d is in µm.

MICROSCOPIC EXAMINATION PROCEDURE TO REVEAL MICROSTRUCTURAL DETAILS

Three metallographic specimens are prepared and examined by each group of students. Microetching techniques are used to reveal general microstructure in Ni-Ti alloys. Ni-Ti alloy is treated with following three chemical etching reagents to get the best possible results. First, the etchant is prepared by mixing 50 ml HNO_3 with 50 ml acetic acid. Ni-Ti alloy (after getting a mirror surface finish from standard polishing techniques) is immersed/swabbed for about 30 s. Second reagent was prepared by mixing solutions of 10 ml HF, 25 ml HNO_3 and 150 ml water. The sample is swabbed for about 30 s. Electrolytic etching is tried as a third technique for revealing general microstructure in Ni-Ti alloys. The electrolyte consists of 5 ml acetic acid, 10 ml HNO_3 and 85 ml water. The electrolytic etching is carried out at 1.5 V for 60s.

CONCLUSIONS/REMARKS

- At the outset, the competency based curriculum is vital for teaching dental materials. Amongst teaching methodologies, discussion model and lecture quiz approaches are considered as effective tools for learning dental materials.

- Laboratory experiments on dental materials are determined useful for students to learn and appreciate evaluating mechanical and microstructure properties. These laboratory experiments are designed specifically to focus on learning skills and creative thinking among students that will be helpful during their professional practice of engineering/science.

- Specific design of experiments for carrying out mechanical tests on very thin specimens of dental materials is particularly challenging. This enhances the skills on hands-on experience and creative thinking of students. Microstructure examination of very thin dental alloys requires careful preparation of specimens and specialized etching technique for revealing microstructure details.

BIBLIOGRAPHY

[1] Whitters, C. J., Strang, R., Brown, D., Clarke, R.L., Curtis, R.V., Hatton, P.V., Ireland, A.J., Lloyd, C.H., McCabe, J.H. and Nicholson, J.W., *Dental materials-1997 literature review*, 27(6**),** 1999, 401.

[2] Whitters, C. J., Strang, R., Brown, D., Clarke, R.L., Curtis, R.V., Hatton, P.V., Ireland, A.J., Lloyd, C.H., McCabe, J.H. and Nicholson, J.W., *Dental materials-1996 literature review*, 26(3), 1998,191.

[3] Iijima, M., Ohno, H., Kawashima, I., Endo, K. and Mizoguchi, I., *Mechanical behavior at different temperatures and stresses for superelastic nickel-titanium orthodontic wires having different transformation temperatures*, Dent Mater, 18(1), 1992, 88.

[4] Sachdeva, R. C. and Miyazaki, S. *Superelastic Ni-Ti alloys in orthodontics*, In: T.W. Duerig, K.N. Melton, D. Stockel, C.M. Wayman, Editors. Engineering aspects of shape memory alloys. Butterworth-Heinemann, London, 452, 1990.

[5] Miyazaki, S. and Otsuka, K., *Development of shape memory alloys*, ISIJ Int, 29, 353, 1989.

[6] Burrow, M.F., Dodds, A.E., Problem-based learning in a traditional curriculum: The case of Dental Materials Science. JOURNAL OF DENTAL RESEARCH 82: 106-106 Sp. Iss. CDEC, 2003

[7] Davis, M.H., AMEE Medical Education Guide No.15: *Problem-based learning*: *a practical guide*, MEDICAL TEACHER, 21:130, 1999

[8] Greenberg, P.B., Elliott, S.L., Tested teaching tips, MEDICAL JOURNAL OF AUSTRALIA 180 (8): 376-377, APR 19, 2004.

[9] Brantley, W.A. and Eliades, T., *Orthodonic Materials: Scientific and Clinical Aspects***,** Thieme Medical Publishers, 2000.

[10] Rock, W.P., O'Brien, K.D., Stephens C.D., *Orthodontic teaching practice and undergraduate knowledge in British dental schools*, Br Dent J. 2002 Mar 23;192(6):347-351.

[11] Schweitzer, K.L., Cohen, P.A., Teaching dental materials using the personalized system of instruction, J Dent Educ. 1987 Oct;51(10):589-93.

[12] *Commission on Dental Accreditation Standards for Dental Education Programs*, Chicago: American Dental Association, 1986.

[13] Snow, R.E., *Toward Assessment of Cognitive and Conative Structures in Learning*, Education Researcher, 1989.

[14] Gaver, D.P., Dee, KC, Hart, R.T., and O'Neal, E., *Implementing Experiential Learning in Biomedical Engineering*, a proposal to the National Science Foundation, 2000.

APPENDIX

Course contents

1. **Review of current materials technology**: Plastics, Advanced composite materials, Ceramics, Superconductors, Materials in medical engineering.
2. **Mechanics of materials**: Advanced continuum mechanics, Basic shell and plate theories, Stress analyses of cylinders - thick and thin walled cylinders, Torsion, Bending. Advanced and computational mechanics of materials.
3. **Advanced fracture mechanics**: Summary of basic problem, Mechanisms of failure, Energy considerations, Plane stress and strain, Linear elastic and elastic-plastic fracture mechanics, Stress intensity factor, J-contour integral, Fatigue, Design with fracture mechanics.
4. **Intelligent materials**: Primitive functions of intelligent materials, Intelligence inherent in materials, Biomimetics.
5. **Smart materials and structural systems**: Actuator materials, sensing technologies, Microsensors, Hybrid smart materials, Reactive actuator-based smart structures, Smart skins, Active sensing and reactive smart structures, Examples in active vibration damping.
6. **Optical fibers**: Types of sensors - interferometric and polarimetric , Fiber optic nervous systems .
7. **Piezoelectric materials & shape-memory materials**: Fundamentals, Integration with smart materials, Applications of shape memory alloys, Continuum applications: structures and machine systems, Discrete applications. Introduction to neural networks.
8. **Micro-Electro-Mechanical Systems (MEMS) & Molecular manufacturing**: Application of above systems and technologies to MEMS and the philosophical relationships of MEMS technologies to molecular manufacturing.