INTERGRATED APPROACH IN MATERIALS AND ENGINEERING DESIGN

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REGIONAL SYMPOSIUM ON ENGINEERING EDUCATION 2007
14 FEBRUARY 2007
UNIVERSITI MALAYA

Perp. UPS/PP

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2. Fakulti/Jabatan: FKMP - JKBR
3. Tajuk Seminar/Kursus/Bengkel/Persidangan/Simposium : Regional Symposium on Engineering Education

4. Tajuk bahan yang diperolehi :

i. Proceeding CD.
ii. Paper
iii. ______

5. Tarikh Seminar/Kursus/Bengkel/Persidangan/Simposium : 14.02.2007

6. Tempat : Universiti Malaya.

04.03.2007
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Integrated Approach In Materials and Engineering Design

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ABSTRACT

Engineering design is a process of problem solving by using engineering principles or science which is conducted systematically. In design process, a careful consideration is required about the materials from which a product is to be made. As the number of available engineering materials by the 2000s is large, a design engineer should have a comprehensive knowledge not only in engineering science but also in material science. Therefore, the Department of Materials and Engineering Design, FKMP-KUiTTHO is proposing a master degree program in engineering design which its curriculum is aimed to provide the participants with knowledge about design and materials simultaneously. Integrated approach in design and material will be applied in the learning process through subject assignments and research projects in which the participants will be intensively involved. This paper will give description in detail about the integrated concept and examples of current researches and academic projects which have been conducted. The master program is also considered to accommodate non mechanical engineering graduates who intend to deepen their expertise in engineering design.

Keywords: Integrated approach, materials selection, engineering design

1 INTRODUCTION

The importance of material selection in engineering design is unarguable. Normally, the application of a material follows the design, but sometimes it is another way round, a new product was made possible by new materials, such as in Teflon case, in which the material was first incidentally invented and the applications were then searched for. However, today, in the age of advanced materials, in which the number of available materials is about 80.000 and at least 1000 different ways to process them [1], the design engineer would need information about all these if he is to optimize the choice. At this point, a standard knowledge in materials selection is considered insufficient because it tends to lead the engineer to consider only the conventional ones.

At the moment, materials are classified broadly according to their mechanical, chemical, physical and other highlighting specific properties. Materials handbooks cover data about strength, stiffness, corrosion resistance, density, thermal conductivity, etc, and link these to the applications. Since design problems are considered as highly dependent on the application, knowledge in the application (aerospace, automotive, marine, etc.) is very important for engineers to enable them to judge the appropriateness of materials, particularly regarded to their operating environment. Beside of that, since material, process and design are interrelated, the choice of material is not independent, because this will decide the way the material will be processed in order to meet design requirements.

Considering all the above mentioned aspects and that engineering design is an intellectually demanding activity, engineering education should enable its participants to have self experiences in design projects, whether in individual or in team work tasks, in which they integrate intensively their knowledge in materials and engineering principles as well as their creativity to obtain design solutions. Education should also awake their awareness to recognize current important issues, new material choices, updated techniques and methods in design process and material selections, so that the participant will manage to analyze and optimize the design, especially in mechanical engineering field.

2 THE NATURE OF ENGINEERING DESIGN

By its nature, design is problem solving process with open ended solutions. The initial requirements lead to a first selection that suggests modifications to the requirements. If they are insufficiently restrictive, too many solutions are obtained; if over-restrictive, none may remain and we need to develop a completely new solution. As a result, the designer must correct, modify and re-think his requirements and repeat the selection procedure. However, at the end, there are many unsolved problems in the "optimal selection".

The above design procedure focuses on identifying components and materials to fulfill functional requirements, which is generally necessary at the early stage of engineering design. At this stage, the identified materials may not be very specific. Often, they are only in very rough form, being restricted to some sorts of materials, or materials with some functional properties. Sometimes, the materials are not determined at conceptual design stage, even after the components of the design have been fully determined. The designers often need to determine or to design the required components as well as their configuration simultaneously. Therefore, the whole thing could become complicated as the materials selection is combined with the design of the components, and the configuration of these components. Therefore, it is necessary that materials selection to be done again at the detail design stage.

At the end of a design process, all the design requirements are checked to ensure that the functional requirements of a design are fulfilled effectively and efficiently, and a number of design constraints are satisfied, such as the constraints on the availability of materials and components, the constraints on the size (dimensions), mass and other properties of the components, as well as constraints on the system outputs. These requirements and constraints are often called as the design metrics. The output of this problem solving process has to include the determination of the physical structure of the product, such as the geometric of components and their configuration, and the chosen materials of these components.

3 PROBLEMS BY MATERIALS SELECTION

Materials are generally regarded as an attribute of components in a design. However, there are several situations where materials play a same role as that of components in delivering a required function, such as when specific properties of a material are exploited to fulfill a functional requirement. For example, heat treatment on steels which is done in order to fulfill the requirement of surface hardness in cutting tools. Here, the properties of the materials decide the cutting performance.

Materials properties can be categorized in a number of ways, but conventionally, materials are classified into groups with similar properties, processing and common fields of applications. This leads to the general classification, i.e. Metals, Ceramics, Glasses, Polymers, Elastomers and Composites. The composite class is unique because it provides combinations of properties from the other classifications. Although each category of materials is associated with characteristic properties (mechanical, physical, etc.), there is often overlap and contradiction between categories, as a result, confusion in decision making could occur.

Since no single material can meet all the design, a solution may be found by combining two or more materials to form a hybrid 'multi-material'. There are plenty of examples when materials are applied in combination in engineering design. Some common situations are: first, single components consist of several different materials, which are in discrete and integrated forms, such as a heterogeneous flywheel made from stainless steel and copper. The second is combination of components, each with similar or dissimilar materials. This is the most common situation in engineering design such as ball bearing that consist of the housing, the bearing itself and the shaft. The three components could be made from different materials.

In reality, most of practical design problems involve materials in combination because the multiple materials jointly contribute to the performance of the system to produce optimal design metrics. As mentioned before, the selection of materials is therefore coupled with the design of the components and its configuration. Deng and Edwards[2] have summarized two categories of materials selection problems: first is the materials selection based on the required material properties, and the second is the materials selection based on the required design metrics, where the requirements on material properties are coupled with those on the physical structure and the relevant structural properties.

The existing materials selection strategies generally are used for the first type of problems, in which materials are selected by their given materials properties. There are already several of formalized methods to support selection of individual materials, where the requirements on the materials are known. In the early stages of the design process, the number of materials under consideration is quite large. As the design progresses the number of materials reduces and the data becomes more refined until eventually a candidate material is selected and used.

The crux of materials selection involving materials in combination, in the other hand, is to determine the respective properties or attributes of the materials and components, whereby these properties should jointly contribute to the optimal design metrics. This requires a new technique or new method of material selection to enable design engineers to consider materials in combinations and the geometry of the multi-materials simultaneously.

4 THE INTEGRATED APPROACH AND FUTURE CHALLENGES

4.1 The Integrated Approach

Engineering design is a very complex process, involving various stages of activities, most of which are iterative and various aspects of design information are interconnected, such as design requirements, constraints, conflicts, compatibility, functions, behaviors, structural components, materials, interactions, enabling principles, knowledge in various forms and so on. As a result, it is not possible for any single theory, or model, or methodology to cover all these issues.

There are already several formalized methods to help the determination of design solution and materials selection. However, the subject of engineering design in most of bachelor degree in mechanical engineering discusses only the well-recognized systematic methods from Pahl and Beitz [3.], Hubka and Eder [4.] and Pugh [5.]. Actually, there are several existing integrated design methods such as: and Suh [6.] for axiomatic design theory. Some focus on specific aspects of design, or specific stages of design, or specific areas of designs, e.g., Ljungberg [7.] proposed an integrated product materials selection (IPMS) model, specifically for materials selection related product lifecycle design and development. Li [8.] developed also integrated material selection method applied for composite materials in structural engineering. These new engineering design procedures should be introduced in master degree program in order to give the participants more tools to solve design problems.

Figure 1 shows the concept of integrated approach which is used in our master degree program. It can be seen that material properties is intersection of the two domains. For a component made of a single material, material selection always chooses first the type of material based on its properties, then check component's configuration, and finally check whether the component can satisfy its functional requirements determined by design. Conventional single materials, however, cannot satisfy more critical requirements for special functions of components or products in high-tech applications. For the component made of multi materials, material selection process has to be reversed, i.e., from its functional requirements in certain applications to the component's configuration and then to material properties, and to material microstructures and/or constituent compositions.

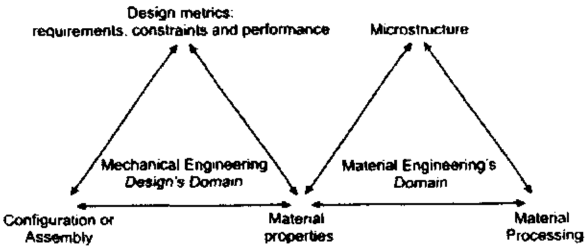

Fig. 1. Concept of integrated materials and engineering design

From the material engineering domain, the properties of material cannot be separated from the process by which the shape and the geometry of the component will be made real. A car wheel can be produced either by forging or by die casting, but the properties of the end product will be different, consequently, the functional requirements will be not equal too. There are many ways of creating components (shaping, joining, finishing, etc.), but choosing the optimum route is already difficult and achieving the required properties of the end product is much more difficult. In an integrated approach, materials processing should also be taken into account.

4.2 The High Tech Application

Today, due to the development and applications of high technologies, there is a need for designing components to satisfy the critical functional requirements from their applications. The phrase of functional materials is more often used to distinguish passive functional materials from active materials. Passive materials only respond to a signal, on the other hand, active materials are able to respond and to transmit the signal. The signal can be thermal, mechanical, magnetic or electrical. Active materials are applied in sensors and electronic devices and the application of this type of materials is increasing.

Data for passive functional materials can be found in handbooks and databases. The methods for selecting them and the processes required to shape them are simple extensions of those described above. Active functional materials pose greater challenges. First, high tech components are made of several different homogeneous and/or heterogeneous materials. The coupling between two different kinds requires a predictable description or at least a determination of more than one interaction coefficients. Second, the response often depends on the shape or can be magnified by shaping, so that selection cannot be separated from shape. Third, the performance they offer to act as sensors and actuators includes the frequency at which they can be driven, the power they can convert and the efficiency with which they do so.

For such components, materials with different microstructures and/or constituent compositions for required material properties are connected through bonding or sintering technique. Different interfaces are thereby produced between adjacent material regions. For example, the structure of microelectronic components has been changed from a single-layer film to a several-hundred-layer structure, which improves the integration extent of components. But, due to the thermodynamic mismatch of material properties, the thermal stress concentration is produced on the interfaces and the system reliability is reduced when the working temperature is changed. Therefore, selecting suitable materials with good chemical stability and physical matching extent for adjacent material regions is one of the key issues for designing components made of multi-materials.

4.3 *Failure and Life Assessment*

Component life is normally not considered in the conventional material selection methods. As a general rule, the life of a product is limited by creep, by fatigue, by corrosion or by wear. The mechanisms of creep and fatigue depend only on the properties of the material and loading condition. Data for creep and fatigue behavior can be added in database of material properties. Corrosion and wear are more difficult because they depend not only on the properties of the component-material but also on the environment in which the materials are used (the corrosive medium), or on the materials surfaces interaction and the lubricant (if applied) between.

There are several available methods for safe design for certain materials under conditions of creep, fatigue, corrosion or wear. However, resistance values of all the material candidates should be evaluated and compared. Since standard testings for creep, fatigue, corrosion and wear are time-consuming, the only practical way is to develop semi-empirical models for each mode of failures and fitting them to the incomplete data in available databases.

Design and material selection procedures which include failure mode and life assessment should be brought in the engineering design curriculum for master degree because today, safety and reliability aspects has been more and more important. The decisions made at the early design stages based on safety assessment will probably have a more significant impact on the performance of an engineering product than those at any other stages in its lifecycle.

4.4 *Green Design Issue*

Ecological impact has become an additional design metric to be optimized in all branches of engineering, along with functional performance and cost. Eco-design can be associated with the innovation and refinement of the material, with the manufacture process to produce the product, with the use of that product and with its disposal [9].

However, eco-design could also create contradiction. Well-intentioned design to reduce the impact of human and environment may have the effect of increasing it in another. This is a system problem, not one of isolated event. For example, in light structures, aluminum is considered more environment friendly than plastic/polymer, but aluminum is far more energy-intensive to produce and to manufacture than plastic. So far, even though limited progress has been made, this has created new opportunities for innovations.

5 RESEARCH PROJECTS IN ENGINEERING DESIGN IN KUITTHO

5.1 *Development of Catalytic Converter*

The main function of catalytic converter is to filter gas released to the environment by the engine in order to reduce harmful emission (CO, NO_x, HC). When exhaust gas flows into the inlet pipe of the converter, oxidation and reduction reactions are expected to occur inside and produce harmless gases (H_2O, N_2, CO_2) which flow out through the outlet pipe. This was one of design projects driven by environmental issues. The development of catalytic converter was a project dealing with multidisciplinary, which involves materials engineering, mechanical design principles, fluid dynamics, chemical reactions and numerical modeling. Figure 2 show the milestone of the project.

Catalytic converter has four main components, i.e. casing, substrate, washcoat and catalyst. Washcoat stores oxygen and provide a layer where the reactions take place. Catalyst helps increasing the reaction rate. Substrate provides housing for catalyst and washcoat and a substrate is designed to ensure that the gas flow will be laminar. Casing provides housing for the whole system.

The project in Kuittho started in 2004 by conducting conceptual design including materials selection. Conventional engineering design procedure was applied and variant concepts were determined by selecting amongst available solution principles for the four main components. Prototypes of substrate have been made from commercially available high temperature Aluminum alloy, i.e. Ferro Chrome Aluminum. Here, beside of manufacturing techniques, such as metal working and joining, the performance of the substrate to reduce harmful emission was then assessed.

YEAR	PROJECT	DETAIL
2004	1 Project Assignments of Engineering Design Subject	Conceptual Design of Catalytic Converter
	2 Projek Sarjana Muda (PSM)	Effect of Zeolite in an Air Filter for Automotive Application
		Effect of Zeolite in a Catalytic Converter
2005	1 Projek Sarjana Muda (PSM)	Development of a Metallic Monolith for Catalytic Converter
	2 Projek Sarjana	Development of High Temperature Material Fe-Al Based Alloy using Powder Metallurgy and Surface Treatment
2006	1 Project Assignments of Engineering Design Subject	Engine Test Rig for a Catalytic Converter
	2 Projek Sarjana	Design and Numerical Analysis of A Catalytic Converter by using CFD
[illegible]	[illegible]	[illegible]

Fig. 2. Milestone of the development of catalytic converter project.

This 24 month project was focused in the design of substrate and washcoat's material, therefore, studies in the optimization of substrate design and fluid dynamic modeling for master degree has been done by using computational fluid dynamic software.

Considering that the high temperature corrosion resistance of the material had to be improved and that the fabrication of the substrate from band or sheet raw material of commercial FeCrAl was difficult, a study has being conducted for a master degree in producing FeCrAl by using powder metallurgy process in order to obtain better corrosion and high temperature resistance. By using this process, the properties of the product could be varied according to the raw material and process variables. In this case, the material selection process was reversed, instead of starting from material properties, selection was started from functional requirement and the properties were modified according to the requirements.

5.2 <u>Development of Controllable Airship</u>

The main objective of this project was to design a low cost non rigid airship with static and dynamic stability and it can be controlled remotely. The function of this airship is for aerial surveillance mission, such as to monitor area of accident scene, flooding and traffic congestion. As most of the monitoring studies require low speed, low altitude data gathering platforms, a stable remote airship is here suitable to employ.

This project could be considered as multi-disciplinary because it involved engineering design, materials, aerodynamics, light weight structure, and control system. An airship has four main components, i.e. hull or envelope, propulsion, tail structure and control equipment. Students from undergraduate and postgraduate program were involved in this project. Figure 3 shows the project in detail.

PROJECT	DETAIL	STATUS
Project Assignments	Camera Mounting Prototype	Finished
	Fin's Mechanism Prototype	Finished
	Airship's Hull Fabrication	Finished
	Fin's Structure and Detail Mechanism	Finished
Projek Sarjana Muda	Aerodynamic Study by Using CFD	Finished
	Stress Analysis on Airship's Structure	Finished
	Telemetry System on Airship	Finished
	Control System on Airship	Finished
Proposed PhD	Airship's Dynamic Stability Model	Proposal

Fig. 3. Milestone of the research project "Development of Controllable Airship"

Conceptual design including material selection was done by using conventional engineering design procedure in which concept variant was established by choosing amongst available solution principles. A prototype of the chosen variant was built and the performance was assessed in a wind tunnel. Static and dynamic stability of the airship was analyzed numerically. Beside of that, surveillance and control system have been installed.

5.3 *Design of Tool and Die for Stamping of High Strength Steel*

The application of high strength materials increases due to the demand to the replace weight with strength in structures. However, as the design, material and process are interrelated, adjustments are here required.

This research project is planned to be carried out in May 2007 and the main objective of the study is to optimize the stamping process through numerical simulation and build a prototype of the optimum geometry and configuration of tool and die will be then built and the performance will be then assessed. Here, the design process of the tool and die is dictated by the sheet material, i.e. the advanced high strength steel. Knowledge about material, manufacturing, applied mechanics and numerical simulation are required.

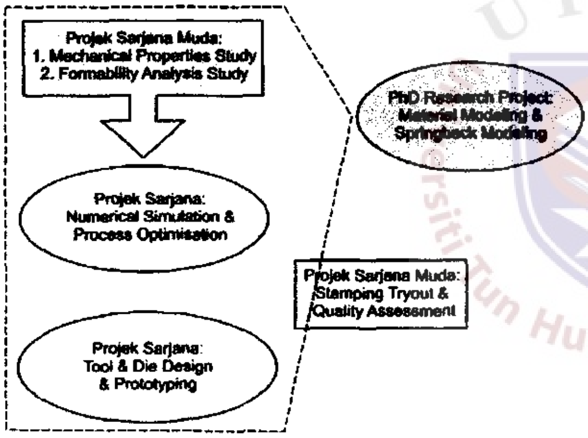

Figure 4. Breakdown of the project "Design of Tool and Die for Stamping of High Strength Steel

This project will involve from undergraduate and post graduate students. Figure 4 shows the topics and the scopes for each title in general. Properties of high strength steel materials including its formability will be investigated by undergraduate student. Process simulation will be conducted by a master student to obtain the best design and a master student is planned to carry out the fabrication of the prototype. A topic in applied mechanics focusing in developing material constitutive equation and springback modeling will be offered as PhD research project.

6 CONCLUSION

Previous sections have given an overview of the current available material selection techniques and formalized methods of engineering design. Considering the future challenges, such as the application of multi-materials, high-tech products, green design, product safety and life assessment, students, especially in master degree, should be introduced with the integrated approached, instead of the conventional methods.

From the projects mentioned above we have gained knowledge, not only the substances of the mechanical engineering disciplines, but also about the wide scope of engineering design task. In catalytic converter project, we learned about the interconnection of engineering design, choices of materials, process manufacture and the whole cycle of product development process. From the project about controllable airship, we learned about interdisciplinary contents of in an engineering design product and from the project about tool and die design, we expected to get more understanding about the functional approach in design and material selection for new choice of materials.

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