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Concurrent engineering approach in the development of composite products: A review

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ABSTRACT

Concurrent Engineering (CE) is regarded as a systematic design approach which integrates concurrent design of product with the related processes which is able to accomplish product that can be produced at lower cost, shorter time and with higher quality and this achievement was termed as cost, time and quality (CTQ) improvement. Since its establishment, CE philosophy was well implemented in product development with traditional materials such as metals but up to date, the work on CE in composite product development is still limited. Hence, a review on the implementation of Concurrent Engineering (CE) approach in the development of composite products is presented in this paper which includes review of various studies of CE techniques in composite product development. In addition, the relationship between CE and Pugh total design method is discussed in the context of composite design. Moreover, publications related to materials selection, life cycle analysis and sustainability issues of composite materials are also reviewed whereby a section is devoted to highlight previous work on materials selection using Analytical Hierarchy Process method. It was observed that materials selection of composite materials is a very important activity as far as CE in composite product development. The use of various techniques and computer aided materials selection tools such as Analytical Hierarchy Process has helped designers to select the most optimum composite materials for engineering components. Furthermore, based on current trends in composites product development, the role of CE is expected to be more crucial to assist composites designers in achieving the design requirements from various stakeholders effectively and efficiently considering the expanding range of composite materials availability as well as realizing new potential for biocomposites applications through introduction of innovative alternative problem solving methods as part of the CE family.

1. Introduction

Concurrent Engineering (CE) was coined by Institute for Defense Analyses (IDA), USA [1] and it was defined as:

> A systematic approach to the integrated, concurrent design of products and their related processes, including manufacture and support. This approach is to cause the developers, from the outset, to consider all elements of the product life cycle from concept through disposal, including quality, cost, schedule, and user requirement.

Traditional approach in product design and manufacture considered only limited information on the manufacturing issues. Therefore CE approach provides the solution for this problem. CE is a way to reduce the lead time between the start of a design and the manufacture of a product by ensuring that manufacturing issues are considered from the beginning of product design [2–5]. In product development process, the departmental barriers between design and manufacture should be removed in order to achieve a product that can be produced at lower cost, and shorter time and with higher quality and this achievement was termed as cost, time and quality (CTQ) improvement [6,7]. CE philosophy was well implemented in product development with traditional materials such as metals [8,9] but the work on CE in composite product development is still limited.

This paper is concerned with the implementation of CE in composite product development. The purpose of the publication of the paper is to fill a gap of knowledge between the fields CE and composites. In many cases, there is a missing link between these two topics. Activities under the umbrella of CE such as materials selection, total design and life cycle analysis is also presented.

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2. The use of CE in composite product development

The implementation of CE is very important in the development of composite products because majority of composite products are developed based on tailor made design; i.e. while a designer is designing the products and selecting the materials for the product, manufacturing process issues are studied during the early stage of design process. The design and manufacture of composite products cannot be treated like metals. Composites require not only an understanding of the material properties but also the knowledge of how they are made. The properties of composites depend very much on how they are being processed. Because of this, the manufacturing process must be considered early in the design process. The engineers responsible for fabricating the product must be involved in the design of the components [10]. Such consideration is in fact the essence of CE.

However, the term CE itself is understood differently by different individuals. Many people believed that CE is computer. According to Prasad [2], CE can be divided in team oriented CE and information technology (IT), particularly knowledge-based engineering (KBE) oriented CE. In composite, both approaches of CE can be adopted very well.

CE necessities simultaneous consideration of the various components life-cycle issues and by involving engineering designers, stylists, tool makers, component and material suppliers, processing engineers, material engineers, accounts, sales personnel and managers. This approach is very crucial in the composite manufacturing industry in order to avoid making costly changes in the final stage of the product development. The development of composite components using CE technique requires the involvement of all elements of the component life cycle from market investigation through sales including performance, cost and user requirements and should involve integration various IT tools [11–13]. The implementation of CE in the development of composite components will result in the reduction of manufacturing cost and improvement of performance.

The nature of composite product development requires the design of component as well as manufacturing process at the early stage of design process makes it fits within the definition of CE. While in the recent years, the emphasis in product development is the concurrent design of product and manufacturing process, composite industry has already implemented such ideas knowingly or unknowingly. It is very difficult to design composite product without designing the materials and without knowing the manufacturing process at the early stage of design. In the case of polymer composites, whatever the manufacturing technique will be and whether it is injection moulding, resin transfer moulding, filament winding, hand lay-up, spray lay-up, autoclave moulding, vacuum bag moulding, or pultrusion, the knowledge of composite materials and their constituent materials are required at the early stage of design process. It is equally applicable whether the fibre system is continuous or random, or in unidirectional, bidirectional woven or multidirectional woven form. In all cases, they have to be decided early in the design stage. It may be some exaggeration in this statement, but generally speaking, composite material design and manufacturing process is a good example of Design for Manufacturability (DFM) implementation.

One of the earlier publications on DFM or CE for composites was published by Gandhi et al. [14] where they proposed simultaneous incorporation of material selection, the part geometry and the constraint and characteristics of the manufacturing processes in the development of composite components. By taking advantages of fibre volume fractions, spatial distribution of the fibres, fibre orientations, and lay-ups associated with each manufacturing process, it was anticipated that CE could be used as a means to produce high quality composite components.

Cong and Zhang [15] developed integrated knowledge framework that performed quantitative composite manufacturability evaluation. Despite high anticipation from Gandhi et al. [14] about the effectiveness of CE implementation in composite manufacturing, Cong and Zhang [15] in 2012 had emphasized DFM or CE in composites is still at its infancy and very limited work had previously been carried out to address this issue. This seemingly big gap between the anticipation and reality in CE study in composites is mainly due to the different nature of the fields of studies. Whereas CE is more focus on design and manufacture, composite is more related to materials field of study. Researchers were more interested in the determination of properties and characterization of composites rather than the design and manufacturing aspects of composites, which were regarded to be more abstract in nature. In their study, Cong and Zhang [15] had came up with terms like hierarchical indices and as a case study the idea was used in detecting void formation in autoclave in the development of aerospace components using autoclave moulding.

One of the most relevant papers on the topic under discussion is the work of Kim et al. [16]. They developed a concurrent engineering system for the design and analysis of composite structures comprises various studies like micro-mechanic analysis, material (ply) analysis, buckling and postbuckling analysis, thermo-elastic analysis and composite ply analysis which used among others, finite element software and optimum design using expert system. The system integration was achieved by a user friendly interface in graphic design environment.

Haffner [17] provided DFM or CE guidelines that explain how process selection and part design can lead to cost saving in processes such as hand lay-up, resin transfer moulding, pultrusion, automated tow placement, forming, and assembly. The study focused on the development of cost models for tooling cost, production equipments cost, manufacturing costs (variable cost, fixed cost and unit costs) associated with manufacturing of composite components. The cost modeling concepts studied include rules of thumb, accounting method, activity based costing and process-based cost model. Similar study was also conducted by Eaglesham [18] where he studied activity-based costing by developing design decision support software system to assist companies to improve cost estimation during conceptual design stage. The system is targeting the aerospace advanced composite manufacturing companies.

Walls and Crawford [19] use the philosophy of CE in the development of a carbon fibre reinforced thermoplastic composite transverse floor beam for a commercial jet. Various modular activities with the context of design for manufacture were performed such as material selection, cost comparison, design optimization, and design and manufacturing process selection were discussed. No specific CE model used was discussed in the paper.

Jones [20] reported the work in Lucas Advanced Engineering Centre, UK on CE approach to the design of high performance component in resin transfer moulding (RTM) composite manufacturing process. The CE-RTM design system was developed to integrate design of component, perform and tooling for RTM process. Integration of various software systems such as computer-aided design (CAD), finite element analysis (FEA) and customized software was carried out. Preform draping was simulated using auto-layup draping software and this provided simulation of surfaces obtained from CAD and finite element (FE) mesh data.

Karandikar and Mistree [21] regarded the understanding of the interaction between information during design and manufacture of a component as a major issue in CE. They studied this issue by taking the design of components from composites as a case study. They came up with the integration aid called Decision Support Problems of various major activities like material selection, design