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Computer aided material selection for additive manufacturing materials

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The ease at which products can be manufactured directly from digital data in one step removing the need for tool design or manufacturing set up leads to a scenario where highly individualised and complex products can be created that avoid cost and time penalties enabling products that are competitive with mass produced equivalents. The reality of this scenario is that, although additive manufacturing (AM) offers a real solution to the problem of producing complex or customised products that are competitive with mass produced equivalents, information regarding available AM material and process capability is fragmented and difficult to generate. This stands as a suitable barrier to adopting AM strategies. This paper presents a knowledge system contained within an existing CAD environment, in this case SolidWorks CAD software, which can be accessed within the existing graphical user interface, enabling the selection of appropriate AM materials and process technology from user generated model data.

Keywords: additive manufacturing; CAD; material selection

1. Introduction

Developing a materials and process selection strategy is an imperative part of a design work strategy. A successful selection strategy positioned early in the design stages of a new component development or redesign of an existing component encourages concurrent engineering, making all design activities parallel to one another. As such, a good material and process decision support system can overcome bottlenecks to concurrent engineering including supported early decision making and feedback facilitating technology (Sapuan 2001). By presenting designers and engineers with robust material and process data and by integrating the flow of feedback from design decisions based on the data, products should be better designed, easier to manufacture, functional and optimised.

Additive manufacturing (AM) technologies theoretically should simplify the material and process decision making process and therefore present a new strategy for decision making of this kind. Additive materials are definitively linked to their manufacturing platforms and often a particular material can only be used on a single platform. In this way material and process selection becomes one act. Also, the range of materials and manufacturing platforms for AM is far less than that of non AM. There are an estimated 80,000 engineering materials to choose from and around 1000 different ways to process them (Ashby *et al.* 2004), whereas there are an estimated 135 additive materials available used by around 12 different additive technologies spread over around 44 different technology platforms (Smith and Rennie 2010). However, because AM has not yet matured the information relating to the materials and manufacturing platforms is sparse, fragmented and is inconsistent across the whole range. The meaning of inconsistent data is that particular material property values are not available for all materials; the result of this is that comparisons by numerical methods are biased and exclusive.

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The effect of these factors is that a new strategy for selection of additive materials must differ from a more traditional approach and play to the strengths of what is available to make a comparison. AM, defined as building components one layer at a time, are used to manufacture many end use parts in metals and polymers including many mimicking materials designed to reproduce the properties that might be found in non additive engineering materials (Sercombe and Schaffer 2003, Hague *et al.* 2004, Kruth *et al.* 2004, 2005, Santos *et al.* 2006, Paul *et al.* 2007, Rochus *et al*. 2007). As additive technology improves, produces more materials and becomes more applicable to more sectors, the number of designers and engineers that wishes to consider its use will rise and the rise of AM will have an impact on the way in which component design activity is conducted. Research as to the effect of additive technologies on current design strategy alludes to the fact that one particular impact that additive technologies may have would mean more work is done in a CAD environment up to the stage of manufacturing (Hague *et al.* 2003). Therefore creating a need for all information required to make design decisions up to production to be available in the CAD environment and streamlining the material selection process.

2. Material selection strategy

In terms of current selection strategies for matching material to a design, a review of literature unveils four basic steps that can be observed as a theoretical basis for future work (Figure 1).

Design requirements must be translated into a specification for materials and also processes. Following this, available materials are screened to eliminate those that do not meet the specification. This leaves a sub-set of the original menu of materials that can be considered suitable candidates. A scheme for ranking the surviving sub-set tabulates the most promising candidates and further information provided about the top ranked candidates assists in making an informed decision on a suitable material (Ashby et al. 2004).

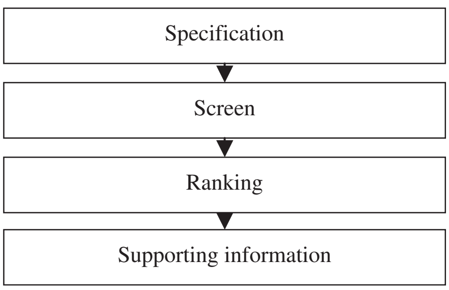

Figure 1. Four basic steps of a material selection strategy.

Within these steps the literature tells us that there are two main components needed for a material selection strategy to exist. They are a comprehensive database of information with specific data attached at each level and some sort of information system, including large amounts of support information in varied formats (Giachetti 1998, Ashby *et al*. 2004). In terms of actual strategy for material selection, three main candidates are defined in literature on the subject. Those of free searching, questionnaire based strategy and case based reasoning sometimes referred to as analogy based strategy.

Free searching refers to the consideration of all material available to a designer. This strategy, when using qualitative analysis is a fast method of searching many materials and offers all available material options to a designer or engineer that fit the criteria they set; in this way it is not at all exclusive in the returns. However, for this strategy to work using qualitative input, it requires precisely detailed data to be entered prior to any search.

A questionnaire strategy will guide a user through some form of structured lines of questioning that leads to a final decision being made. Using this strategy compensates for a lack of knowledge on the users part by implementing the knowledge of an expert or experts in the field, however, this strategy does not innovate – it will only return results that are already known to an expert. New materials and processes that do not exist at the time of the questionnaire design will not feature in the returns. Questionnaires do offer resolution but are difficult to create and maintain with up-to-date information (Giachetti 1998, Amen and Vomacka 2001, Brechet *et al.* 2001, Roa and Patel 2010).

Analogy based selection strategy, also referred to as inductive reasoning and more commonly case based reasoning, uses a database of existing case study examples that are indexed so they may be searched for similar cases to a new problem. Typically the database is indexed with keywords. Case based reasoning is a search tool – it creates nothing nor refines anything, this way it is simple to operate if there is sufficient effort applied to the indexing of the database and the quality of indexed material (Giachetti 1998, Amen and Vomacka 2001, Brechet *et al.* 2001).

With AM materials in mind and with respect to the three component parts of a generic selection strategy laid out above, it would seem that any search strategy based on a questionnaire method would not be suitable as the area of additive technology is new and therefore likely to undergo radical and fast changes in a short period of time and therefore would date questionnaires very easily and with frequency. A combination of free searching and case based information would therefore be a suitable hybrid strategy to adopt as a basis for additive material selection. It is notable however that sufficient material property data for all additive materials are not yet in existence and therefore numerical methods of free search would be inconclusive and exclusive in their returns. As the level of choice compared to non additive materials is much lower, being only a tiny fraction of non additive engineering materials, it may not be a necessarily inhibiting factor as the scale will allow for a more in depth physical search of options rather than having the requirement to compute candidates from a vast sea of options. In this way a weighted case based strategy giving more emphasis on providing case data about available materials coupled with a basic search strategy would seem a likely successful compromise.

3. Computer aided material selection

The following section relates the theoretical framework of a materials selector discussed above to the needs of design for AM. Using traditional theory and combining it with the unique requirements of AM, an AM material selection strategy has been developed and is in the process of embodiment as a software support tool to be embedded into the graphical user interface (GUI) of an existing CAD software package (Figure 2).

Initial stages of development have concentrated on building a sufficient data base of additive materials and embedding the data into the CAD package. A menu can be called within the CAD environment and is placed over the current GUI. Within the called menu can be found one bottom level set of material information listed by material name. At this stage the materials are still listed as a whole set and are not subdivided into families and sub classes. From the menu a single material at a time can be selected, on selection the material properties that are held within a custom materials database are added to the active part, in the case of an open part document, or selected parts in the case of an open assembly document. A secondary operation is performed once the additive material has been selected from the menu and the material properties applied to the part.

This operation applies a custom image map of the selected material to the active part and automatically renders the part using the custom map so the users can view an estimation of the final aesthetic of the part.

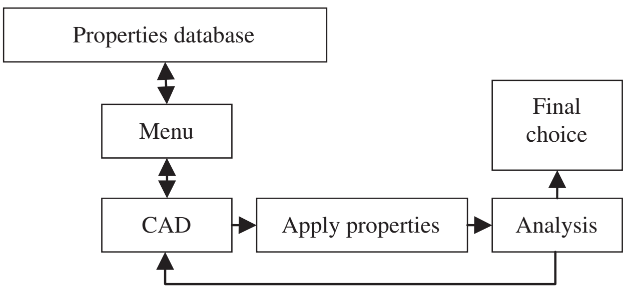

Figure 2. Initial database tool structure.

Prior to the stage of choosing and applying a candidate material to a part the part is analysed to screen AM materials and processes able to manufacture the analysed part that will form a suitable sub set used to further make a decision.

Figure 3 describes how a part in CAD software is analysed for suitability for manufacture using AM. The process of defining the materials subset is automated and operates by traversing the feature tree of a part and returning values for all feature data. The values are then checked against rules that govern which additive materials and processes the part is suitable for. For example, all geometry defining features are checked for values that are under a certain threshold, a threshold which varies for each additive material. Falling under the threshold will eliminate that particular material or process from the final subset as the part has features that cannot be manufactured using the materials for which the threshold is set. The process is iterative and repeats until all features are checked and rules are satisfied leaving the final subset of materials to choose from. From the subset, materials can now be further analysed to find suitable candidate materials to perform the task set out by the design.

As already discussed properties for additive materials are sparse in their availability and have a fragmented structure of sources. Due to this only limited material properties can be included in a custom material property file. At present the custom material file includes values for tensile strength, yield strength, elastic modulus and Poisson's ratio.

The fact that the material properties are sparse for AM materials is not the only limiting factor concerning material selection strategy. The property data for additive materials

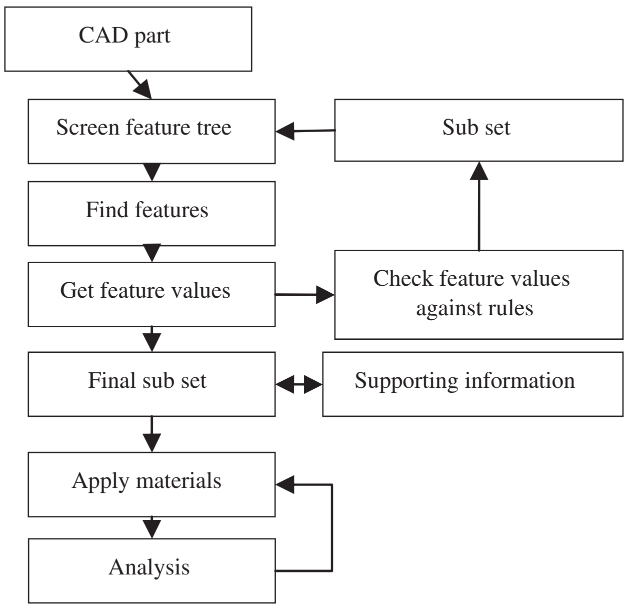

Figure 3. Traversing feature tree to screen all materials.

are not consistent across all materials and so a range of values for one material may not be available for one other or for a set of other materials. For this reason a ranking strategy cannot be used as the only or most important method of comparing additive materials, as inconsistent data is not conducive to a successful ranking selection strategy. However, it remains that a systematic screening process can still take place if only the screening deals with volume constraints of AM platforms and known material property data. It follows that more weight must be given to those components of selection strategy that will not return biased results, such as case based reasoning in this situation. Case based reasoning relies more on the judgement and skill of the user to synthesise the information they require from supporting information. Like all elements of a successful material selection strategy, providing information at the design stages provides a platform for concurrent engineering practice for the new design, by giving the designer the confidence to make design alterations based on the information they have at hand. Case based reasoning strategy as part of an AM materials selection strategy is imperative as in some cases it will reveal more about the material properties than the material property data.

Figure 4 illustrates the basic structure for an AM material selection strategy that weights the use of case based reasoning as its primary decision making mechanism past the screening stage. Level one of the diagram assumes the selection of a candidate material from a subset list resulting from an initial screening which has been performed. Level two presents sets of supporting information related to the particular material selected including any examples of products or components manufactured using the material. Information is weighted toward the use of images, any material property data for the material, press concerning products or the material and a repository of published research involving the material. Manual search can be performed into any of the data repositories, however selecting a particular example case study from the product examples will open all related data to that particular example generating a data bank from the other supporting information, level three in the diagram. It is envisioned that by researching a material in the CAD system the designer or engineer will be able to synthesize a near conclusive solution as to whether the chosen material will satisfy their need from the support information if the answer is not in the material property file. This is a trial and error approach and the process is iterative and controlled by the designer or engineer. Decisions made about the material suitability supported by the case based information can be then checked by applying simulation analysis based on the material property file already applied to the CAD part or by prototyping using the applied material.

In this way the strategy differs from a more calculated method using numerical input and analysis by simplifying the process to a choice from a limited set of materials followed by manual analysis of data. The relatively small amount of available materials and the bias of case study examples to published property data using the materials seem to favour this method of selection.

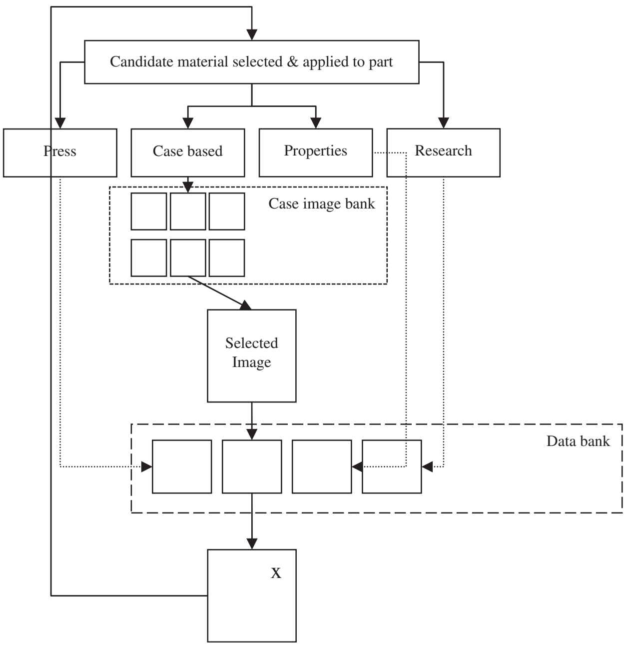

Figure 4. Basic additive manufacturing material selection tool structure.

4. Conclusion

The selection strategy presented here uses a previously published theoretical framework for a basis of a new selection strategy for AM materials. It recognises the specialist requirements of AM, the infancy of the research and how these impacts on selection and the changes AM are predicted to have on the way design activity is conducted.

The collation of research, property data and case information is ongoing in order to create a sufficient repository of information relating to additive materials and to create additive material profiles which will be applied to CAD parts to perform simulation analysis.

A full test of a prototype software tool is needed to further the development of the project.

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