

Virtual Manufacturability Analyzer for Casting Components

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ABSTRACT

There is an increasing demand in automated manufacturability analysis of metal castings at the initial stages of their design. This paper presents a system developed for virtual manufacturability analysis of casting components. The system can be used by a casting designer to evaluate manufacturability of a part designed for various manufacture processes including casting, heat treatment, and machining. The system uses computational geometrics and geometric reasoning to extract manufacturing features and geometry characteristics from a part CAD model. It uses an expert system and a design database consisting of metal casting, heat treatment and machining process knowledge and rules to present manufacturability analysis results and advice to the designer. Application of the system is demonstrated for the manufacturability assessment of automotive cast aluminum components.

INTRODUCTION

Because of high flexibility and near net shape forming, casting components are increasingly being used in many structural applications. Manufacturing a casting component typically involves a casting process, a heat treatment process, and a machining process. The casting process generally relates to the casting of a metal or alloy in a mold for shaping of the metal and/or alloy in conformance with the shape of the mold. Casting processes include sand casting, permanent mold casting, semi-permanent mold casting, squeeze casting, low pressure casting, and high pressure die casting, etc. The heat treatment process generally relates to heating, quenching, and/or holding at a specific temperature or at various temperatures of the casting following the casting process. Various processes for heating, quenching, and holding the casting at a specific temperature or at variable

temperatures may be used. In heat treatment process, various types of quench media may be used to cool the casting in different manners and at different rates. The machining process generally relates to the machining of the solidified castings through cutting, drilling, milling, turning, boring, honing, or other machining methods. It is also contemplated that the manufacturing process may include a geometric designing process that generally relates to designing, or creating, of a geometric design of a casting design. This geometric designing process is usually performed in a computer animated design environment and typically is completed prior to performance of the casting, heat treatment, and machining processes.

Design for manufacturing (DFM) has long been recognized as an important approach for designing and manufacturing high quality products with minimum lead time and cost [1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13]. Unlike other metal forming processes such as sheet metal forming [14, 15], forging [16], and machining [4, 17], however, little consideration has been given to casting design for manufacturability [18]. In many cases, shape castings are designed mechanically to meet desired functional requirements. This is not only because there exists a general lack of understanding of the significance of designing castings for manufacturing, but also because computational systems and tools generally are unavailable for casting designers to access to easily and reliably evaluate the manufacturability of the castings, not to mention the limited capabilities of currently available computational systems and tools [19]. In current casting design practice, casting designers provide casting designs to casting analysts and/or machining analysts for castability and machine-ability evaluations. For instance, in cast-ability evaluations, interpretation of computed results heavily relies on the expertise of casting analysts. In addition, even with availability of sophisticated casting process simulation

modules and user interfaces that provide colorful visualization of predicted results of heat transfer and fluid flow events that occur during casting processes, it remains difficult and time consuming to systematically optimize casting designs without demanding significant human interaction and numerous manual trial-and-error interactions. As a result, conventional casting design processes generally entail lengthy development cycles and low reliability for determining manufacturability due to variations in individual knowledge and experience of those evaluating the casting designs and the manufacturability

This paper presents a system that has been developed at GM to allow casting product designers to quickly assess the manufacturing feasibility of the casting geometry they are designing and further to optimize the design of casting geometries for maximization of manufacturing including castability, heat treatability, and machining feasibility.

CASTING MANUFACTURABILITY ANALYZER

Casting manufacturability analyzer is a computational tool that comprises mainly a 3-D geometry analyzer, a knowledge database, and an expert system performing manufacturability analysis. This unique computational system is fully integrated with UniGraphic. The analyzer can also run by itself to evaluate manufacturability of a casting geometry. Fig. 1

shows the system structure and key logics. The knowledge database contains casting design rules and casting manufacturing principles. The geometry analyzer analyzes geometric characteristics of the casting design to determine a geometric design-ability of the casting design for manufacturing purposes. The casting evaluation module is to find out the potential of forming macro casting flaws such as shrinkage and gas porosity based on the initially designed casting geometry and possible alloy/material and casting process selected. The residual stress evaluation module is to examine the stress level and potential hot spots of cracking in the shape castings during solidification process and quench process of heat treatment. The machining evaluation module is to evaluate dimension accuracy and machining tolerance of final shape castings.

CASTING DESIGN KNOWLEDGE DATABASE

To quickly evaluate manufacturability of a casting at its early design stage, a general design knowledge database is needed. With the design knowledge database, the intelligent searching/matching engine can examine whether the designed casting follows the design rules based on its geometry features and attributes from the geometry analyzer. Fig. 2 shows the control structure and logic of the searching engine system [20]. The searching engine communicates with the knowledge database and with a working memory. The

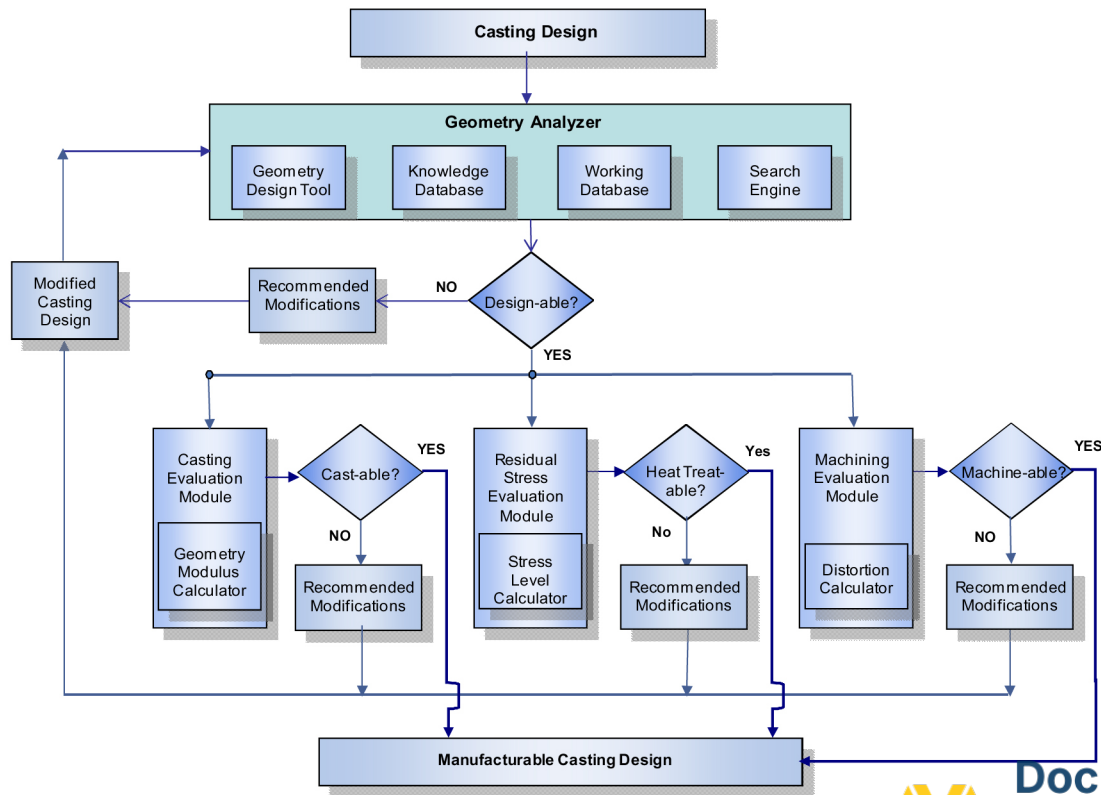


Figure 1. System structure and key logics of casting design analyzer for manufacturability.

forward chaining algorithm is data driven in that it starts from available information, adds new assertions along the way, and then tries to draw conclusions from them. This technique is most commonly used among rule-based systems. As there are many search parameters involved, this search-matching approach avoids the occurrence of combinatorial explosion inherent in brute force or resource-intensive searching, and hence functions in a more efficient manner. The search process itself is directed by a rule interpreter. The design of the searching engine is divided into three central components: a rule set, a working memory which contains the current state of the system, and an inference component which applies the rules based on the state of the working memory. The inference engine determines how to apply these rules, and also determines the order in which they should be applied.

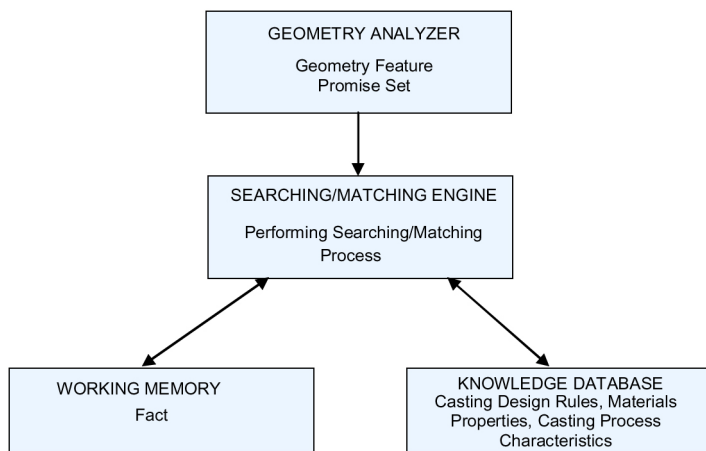


Figure 2. The control structure of the searching engine system.

The general casting design knowledge database consists of a number of casting design rules, materials properties and casting process characteristics. Most metals and alloys shrink when they solidify because solid density is usually greater than liquid density. Therefore, in casting design all dimensions should consider shrinkage. If possible, all sections and members of a component should be designed as nearly uniform in thickness as possible. In addition to considering the minimum thickness for functionality requirements in different sections, the wall thickness should be also satisfactory with the specific alloy/material and casting process selected or determined. For instance, the satisfactory wall thickness ranges from 5 mm to 15 mm for most sand cast aluminum. If design parameters require thicker castings, the system will suggest designer to consider stronger alloy/material and premium casting/heat treatment processes to reduce section thickness. The various casting processes have associated with them different ranges of geometric features that can be produced (including minimum section thickness, maximum wall thickness, and minimum core size, etc.), different achievable levels of quality (including surface finish, dimensional tolerance, and internal

soundness), and different production parameters (including lead time and cost). In cases that various sections with different wall thicknesses have to use, all sections and members of a component should increase in dimension progressively and also should increase to one or more suitable areas where feeder/risers can be placed to offset liquid shrinkage. Sharp corners and non blended transitions from thin sections to thick sections are sources for casting flaws (such as porosity, inclusions and shrinkage). Such areas are also sensitive to cracks and distortion in heat treatment. To avoid sharp corners, a minimum radius of one millimeter is recommended. Radii are also a function of the thickness of the sections that they connect. To increase the likelihood of getting a sound casting the design should call for smooth blending and as large a fillet diameter as possible in intersecting sections.

Drafting is very important particularly in sand castings so that the tooling can be withdrawn from the sand without damaging the imprint. As a good practice the designed casting should allow a draft of at least 1 degree on walls with low aspect ratio and up to 2 degrees when available. For wall thickness, walls thinner than about 3 mm in sand casting design can result in misruns or improper filling.

CASTABILITY CHECK

Castability check is mainly focused on the potential of forming macro casting flaws such as shrinkage and gas porosity based on the initially designed casting geometry and possible alloy/material and casting process selected. The hot spots for possible macro shrinkage are identified based on geometry modulus calculation and characteristics of the alloy and process selected or predetermined. The possibility of forming macro gas porosity is determined from the chosen casting processes, types of molding materials, and internal casting geometry etc. Other aspects of castability, such as minimum castable holes and radius etc., will be examined based on the geometry features and sizes from geometry analyzer using general casting design knowledge database that contains knowledge and design rules of alloy properties, advantages and limitations of various casting processes, molding materials properties, etc.

Possibility of forming large macro shrinkage porosity in a casting can be readily estimated from the hot spot potential. The hot spots are those isolated locations where the solidification times are longer than those of the surroundings. Using modern casting simulation software, the solidification time of various parts of the casting can be calculated quickly without estimation. For a given alloy and casting process, the local solidification time of a volume (V) in a casting is directly related to the local volume-to-surface area (V/A) ratio which is often referred to as equivalent local geometry (section) modulus (M_s):