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Optimal Riser Design in Sand Casting Process Using Genetic Algorithm

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Abstract— Casting design which includes the gating and riser system design has a direct influence on the quality of cast components. The design should provide a minimum volume of gating and riser system but warranting the quality of the casting. Due to the lack of fixed theoretical procedures, the gating and riser system design is carried out on a trial-and-error basis that results in a feasible solution but not always an optimum one. In simulation software the initial riser design has to be fed manually. In this work the optimal riser system design is considered. Genetic algorithm (GA) is used to optimize the riser system design. The fitness function in GA is to minimize the volume of the riser under constrains, that ensures no defect appears in the casting. GA method gives an optimized riser which is 8.13 % lesser in volume, than the riser that is traditionally designed by using modulus method.

Index Terms— CATIA, genetic algorithm, green sand, MATLAB, modulus, riser design, shrinkage defect

1 Introduction

Casting is an important manufacturing process for a variety of industries. Among different casting processes, sand casting is the most widely used process for both ferrous and non-ferrous [1]. The design of castings with the aim at the optimal utilization of material, energy and other resources while ensuring defect-free products [16]. The proper design of riser required to achieve directional solidification is important because improperly designed riser results either defective casting with a shrinkage cavity or lower yield [3]. Feeding is the long, slow process that is required during the contraction of the liquid that takes place on freezing [4]. However, the experimental routes are always better for the design and development of mould and for arriving at the optimum process parameters [8]. But, it is costly, time consuming, and may be impossible in some cases. Therefore, casting simulation process is a convenient way of proper design of gating system. Riser design plays a very important role in gating system design. In simulation software packages riser dimension has to be given manually. This is done by using empirical relations and human experience that provides a feasible solution in most of the case but it will never end up with an optimal solution. Genetic algorithm (GA) can be used to design optimized riser by using the empirical relationships as input along with other parameters.

GA is robust, effective optimization techniques inspired by the mechanism of evolution and natural genetics [2]. It is a method for solving both constrained and unconstrained optimization problems that are based on natural selection, the process that drives biological evolution [11]. The genetic algorithm repeatedly modifies a population of individual solutions [5]. At each step, the genetic algorithm selects individuals at random from the current population to be parents and uses them to produce the children for the next generation [12]. Over successive generations, the population evolves toward an optimal solution [15]. GA can be performed by using Matlab software by using genetic algorithm solver [10]. MATLAB (matrix laboratory) is a numerical computing environment and fourth generation programming language developed by Math Works. MATLAB 7.6.0 R2008a is used for this work. It allows matrix manipulations, plotting of functions and data, implementation of algorithms. creation of user interfaces, and interfacing with programs written in other languages, including C, C++, Java, and Fortran [13].

The genetic algorithm uses three main types of rules at each step to create the next generation from the current population [6]. The general flowchart of the genetic algorithm is shown in fig. 1 [14].

- Selection rules select the individuals, called parents; they contribute to the population at the next generation.
- Crossover rules combine two parents to form children for the next generation.
- Mutation rules apply random changes to individual parents / children to form children.

2 Riser and Riser Design

Riser is a source of extra metal which flows from riser to mold cavity to compensate for shrinkage which takes place in the casting when it starts solidifying. Without a riser heavier parts of the casting will have shrinkage defects, either on the surface or internally. Shrinkage in a mold, from the time of pouring to final casting, occurs in three stages [4].

- During the liquid state
- During the transformation from liquid to solid
- During the solid state

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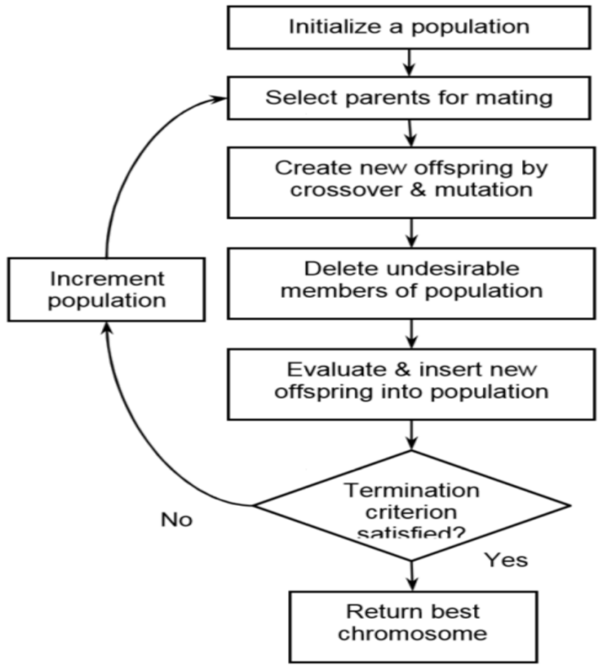

Fig. 1. General flowchart of the genetic algorithm

The first type of shrinkage is being compensated by the feeders or the gating system. For the second type of shrinkage risers are required. Risers are normally placed in that portion of the casting which is last to freeze [18]. A riser must stay in liquid state at least as long as the casting and must be able to feed the casting during this time [20]. The yield of a casting is defined as the casting weight divided by the total weight of metal poured, it is clear that there is a motivation to make the risers as small as possible to still perform their task [19]. Yield percentage is given by following equation [4].

$$\text{Casting yield } (\%) = \frac{\text{Volume of casting}}{\text{Volume of casting} + \text{Volume of gating system}} \qquad (1)$$

Modulus of cylindrical riser is given by the following equation [4].

$$\text{Modulus of riser} = \frac{DH}{4H+2D} \text{ units} \qquad (2)$$

Where, D = Average diameter of cylindrical riser (mm),

H = Height of cylindrical riser (mm).

3 Formation of Genetic Algorithm Problem

The objective here is to optimize the riser size. Therefore, the fitness function for this problem will be minimization of the volume of the riser. The casting which is shown in Fig. 2 is modeled in CATIA software and it is made up of ductile iron (BS2789 Grade 500-7 SG Iron) using the sand casting method practically. 500 is the tensile strength in N/mm^2, elongation is 7 % and hardness 170- 240 HB [17]. Table 1 provides the chemical composition of the alloy that was measured by using a spectrometer. The weight of the casting is 22.49 kg with a volume of 2616197 mm^3 and the surface area of the casting is 398964 mm^2. Modulus of casting is the ratio of volume to surface area which is 7.96 mm for this casting. The shrinkage factor of this material is 2.5% contraction to 2.5% expansion [2]. Surface area of the component is calculated in CATIA software and it is nearly equal to the actual surface area of the component.

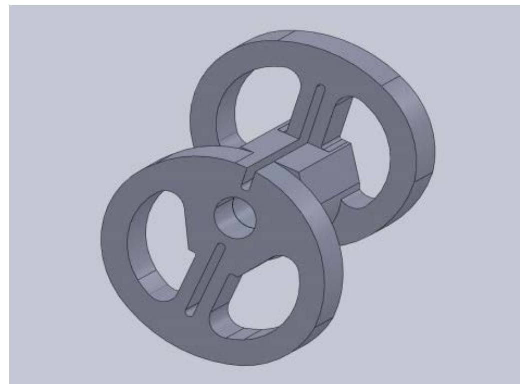

Fig. 2. Model of casting in CATIA

The search space has infinite possibilities for feeder dimensions. GAs gives a methodology for parallel search in the domain of all possible solutions such that the fitness function, which in this case is yield maximization. Inputs are volume, modulus of a riser section and the fitness function. The initial population is selected by a random number generator so that the variables lie within the specified bounds. The yield percentage per component is calculated by using the volume of casting, volume of gating system and volume of risers. So to maximize the yield percentage per component volume of riser must at minimum as possible and it must satisfy all design requirements of the riser. Objective function, it is also known as fitness equation, which is given in below equation

TABLE 1
CHEMICAL COMPOSITION OF GRADE 500-7 SG IRON

Chemical	C	Mn	Si	P	S	Mg	Fe
Composition %	3.55	0.2	2.90	0.8 max	0.01 max	0.07 max	Balance

$$\text{Minimize, } f(x) = V_{riser} = \frac{\pi}{4} D^2 H \qquad (3)$$

Constraints:

$$V_{max} > V_{riser} \qquad (4)$$

$$V_{riser} > V_{min} \qquad (5)$$

$$M_r > 1.2 \times M_c \qquad (6)$$

For the casting,

$$690443 > V_{riser} \qquad (7)$$

$$V_{riser} > 79401 \qquad (8)$$

$$M_r > 1.2 \times 7.96 \qquad (9)$$

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Where, V_{max} = maximum volume of riser (mm³), V_{min} = minimum volume required for riser (mm²), M_c = Modulus of casting (mm), V_{riser} = Volume of riser (mm³), SA_{riser} = Surface area of riser (mm²).

Here V_{min} is the product of contraction factor of material and volume of casting and V_{max} values can be obtained by below equation.

$$V_{max} = \frac{\text{Volume of casting}}{\frac{14-S}{S}} \qquad (10)$$

Where, S is the shrinkage factor.

So by providing these boundary conditions in the GA we can obtain the optimized volume of the riser, which will fulfill all the design requirements of the riser.

4 Genetic Algorithm Solver in Matlab

The following outline summarizes how the genetic algorithm solver works in Matlab solver [7].

1. The algorithm begins by creating a random initial population.

2. The algorithm then creates a sequence of new populations. At each step, the algorithm uses the individuals in the current generation to create the next population. To create the new population, the algorithm performs the following steps [21].

- Scores each member of the current population by computing its fitness value.
- Scales the raw fitness scores to convert them into a more usable range of values.
- Selects members, called parents, based on their fitness.
- Some of the individuals in the current population that have lower fitness are chosen as elite. These elite individuals are passed to the next population.
- Produces children from the parents. Children are produced either by making random changes to a single parent—mutation—or by combining the vector entries of a pair of parents—crossover.
- Replaces the current population with the children to form the next generation.

3. The algorithm stops when one of the stopping criteria is met.

The inputs are coded in "m" files which include the fitness function and constrains. The Genetic Algorithm solver assumes the fitness function will take one input x where x has as many elements as the number of variables in the problem [22]. The coded fitness function is shown in fig. 3 and fig. 4 shows the coded constrains in the MATLAB GA solver.

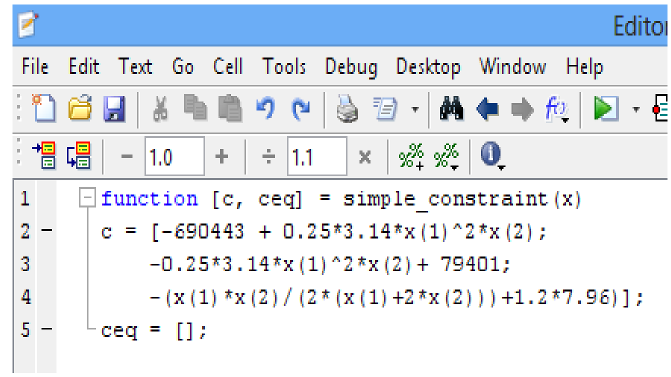

Fig. 3. Coded fitness function

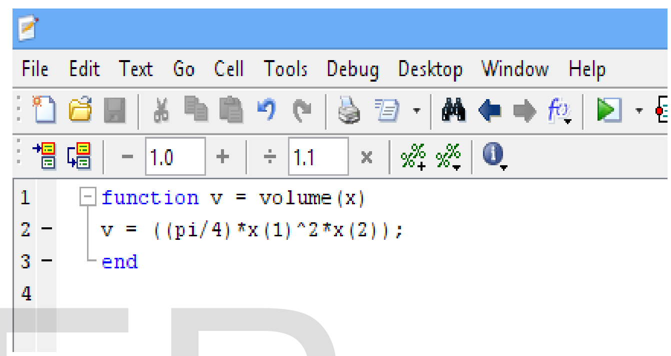

Fig. 4. Coded constrains

The population type is chosen as double vector with a population size of 20. The reproduction the elite count is 2 and cross over fraction is 0.8. Single point crossover is chosen. Mutation is chosen as adaptive feasible because of the presence of constrains. Adaptive feasible randomly generates directions that are adaptive with respect to the last successful or unsuccessful generation with a fraction of 0.05. The stopping criteria is 100 and 39th iteration provided the optimum solution.

4 Results And Discussions

GA solver gives optimized design of riser size. This riser size fulfills all the technical requirements of the riser. From the result (as shown in fig. 5), gives the minimum volume of riser (that is 143563 mm³) and having average diameter 52 mm and height 67.5 mm. Modulus of this riser is 7.96 mm which is sufficient for this casting. GA solver asks user only the volume of component, surface area of component, contraction factor of material and number of iterations only. By feeding these values to program designer will automatically get the design of riser (size of riser) as an output of the program. Generally riser is designed using modulus method. The modulus of casting is 8.77 mm, so required modulus of riser will be 1.2 times modulus of casting. So the designed modulus must have modulus greater than or equal to 9.55 mm. In modulus method for riser design H/D ratio is assumed as 1.5. With this data modulus method give the riser with average diameter 51 mm and height 76.5 mm. The volume of the riser is 156275.77

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mm3. The comparison of these two methods is shown in table 2. Presently used riser has average diameter 60 and height 90 mm and having volume 254340 mm^3.

TABLE 2
COMPARISION OF RESULTS

Sr. No.	Method	Avg. Diameter (mm)	Height(mm)	Volume(mm^3)	Modulus (mm)
1	GA	52	67.5	143563.2	9.55
2	Modulus	51	76.5	156275.7	9.55

The riser design by the Genetic Algorithm method is more efficient than modulus method. It gives 8.13 % less volume than the modulus method for same riser modulus.

5 CONCLUSIONS

MATLAB provides the GA solver that is easy to use. This method can be applied to any standard feeder shape as the volume and area can be calculated by geometrical formulae. As the algorithm is computationally fast and easy to implement, many alternate feeder dimensions can be evaluated quickly. The artificial intelligence technique of GAs can generate an intelligent initial design that can go a long way in making intelligent manufacturing of cast components. As GA is a random selection process it does not require more analytical information. The optimization tool (Genetic Algorithm) can be used in the foundry process to increase the yield of castings. For this component optimized riser size have 52 mm diameter and 67.5 mm height with 143563.2 mm^3 volume. GA method gives an optimized riser which is 8.13 % lesser in volume, than the riser that is designed by using modulus method.

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