Application of Teaching Learning Based Optimization Method for Optimization of Process Parameters to Minimize Volumetric Shrinkage of Wax Pattern in Investment Casting

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Abstract— In this paper Teaching-Learning-Based Optimization Technique has been used for optimization of combination of process parameters, to minimize volumetric shrinkage of wax pattern in Investment casting. Regression analysis has been done using Minitab 18.1. Moldflow adviser has been used as simulation software. Validation of results has been also done by Teaching-Learning-Based Optimization method over Taguchi method.

Keywords: Teaching-Learning-based Optimization, wax pattern, volumetric shrinkage

I. Introduction

Teacher learning based Optimization (TLBO)" is an efficient optimization method for optimization of mechanical design problems, proposed by R.V. Rao [1]. TLBO is a population based optimization method which is based on impact of the teacher on learners.

TLBO utilizes a population of solutions to get optimum solution. Group of learners are known as population. Two phases are considered in this method. The first one is teacher phase and second is learner phase. The "Teacher Phase" includes the knowledge gain by learners from teacher and the "Learner phase" includes the knowledge gain by learners interacted with each other. The teacher is highly knowledgeable person by whom learners learn and gain their knowledge. The quality of teacher is an important factor which effects on the consequence of the learners.

The effectivity of TLBO method had been checked by conducting analysis on many constraint bench mark test function with different characteristics, different bench mark mechanical design problems and mechanical design optimization problems which have physical applications. The results had been also compared with other population based optimization methods based on best solution, computational effort etc, as in [1].

TLBO method is also used for large scale non linear optimization problems for finding the global solution, as in [2].

II. Teaching learning based optimization algorithm

Common control parameters are required for all evolutionary and swarm intelligence based optimization algorithms. These parameters include population size, number of generations, etc. All algorithms need their own algorithm-specific parameters. These algorithm specific parameters should have proper tuning. Improper tuning of these specific parameters affects the performance of the algorithm. Either it increases the computational efforts or produces a local optimal solution. With the tuning of algorithm specific parameters, the tuning of common control parameters are also necessary. By taking these facts on mind [1], [2], [3] introduced Teaching-Learning-Based Optimization algorithm. TLBO algorithm requires only common controlling factors and it does not need any algorithm specific parameters. The algorithm defines two basic modes of learning, as in [4].

- Teacher phase- learner learns or gain knowledge by teacher.
- Learner Phase- learner learns through interaction with each other.

TLBO algorithm contains population and design variables. Population means group of learners and design variables means different subjects offered to learners. Learner's result is analogous to the fitness value of the optimization problem. The best solution of problem is taken as teacher in the entire problem. Teacher phase and learner phase, the two parts of TLBO method and there working are explained below.

A. Teacher Phase

Teacher phase is the phase of TLBO, where learners gain the knowledge by teacher. The teacher teaches learners by his/ her best of knowledge. Teacher improves the mean result or level of learner using his / her skill or capability.

At any iteration i, assumption is taken as T_i be the teacher, M_i is the mean. A good teacher is one who grows up the knowledge of learners at his / her own level. But practically it is not possible to all learners. So teacher T_i tries to improve the mean M_i towards $X_{teacher}$ or his / her own level (i.e. teacher level). The Best learner at whole population is considering as $X_{teacher}$ or M_{new}. To update the existing solution the difference mean formula is used, shown at below [1].

$$\text{Difference\_Mean}_i = r_i\,[\,X_{teacher} - (TF)M_i\,] \quad (2.1)$$

Where r_i is random number. The range of this random number is 0 to 1. TF is a teaching factor which decides the value of mean to be changed. The value of TF is selected randomly with equal probability as

$$TF = \text{round}\,[1+ \text{rand}\,(0,1)\{2-1\}] \quad (2.2)$$

and it can be either 1 or 2. And the modification of existing solution is done using following expression.

$$X_{new,i} = X_{old,i} + \text{Difference\_Mean}_i \quad (2.3)$$

i.e. $$X_{new,i} = X_{old,i} + r_i\,[\,X_{teacher} - (TF)M_i\,] \quad (2.4)$$

Where, X_{new} is the updated values of X_{old}. X_{new} is accepted if it produces better response values or function value than previous value. All the accepted values are maintained as new updated teacher phase which becomes input to the learner phase.

B. Learner Phase

Learner phase is the phase of TLBO where learners increase their knowledge by interacting with each other on their level. The random interactions between learners occur with the help of presentations, group discussions, formal communications

etc. The interaction of knowledge occurs towards high knowledgeable learner to low knowledgeable learner.
Learner's modification is expressed as,
For i = 1: P_n
Two learners X_i and X_j are selected randomly, where $X_i \neq X_j$
If $f(X_i) < f(X_j)$

$$X_{new,i} = X_{old,i} + r_i (X_i - X_j) \quad (2.5)$$

If $f(X_j) < f(X_i)$

$$X_{new,i} = X_{old,i} + r_i (X_j - X_i) \quad (2.6)$$

End If
End For
Accept X_{new} if it gives better function value[1].

III. METHODOLOGY

In this work, result of literature Varun et al. 2019 [6] has been validated by Teaching-Learning-Based Optimization method. For the validation purpose simulated part model, material of wax pattern, process parameters of wax pattern and their levels have been taken as same as in [6].

Reference [6] had performed the design of experiment on the model shown in fig. 1. Taguchi method had been used to optimize the combination of process parameters for minimum volumetric shrinkage of wax pattern in investment casting. The obtained result was mold temperature 10ºC, injection temperature 60ºC, injection time 15 seconds, cooling time 20 seconds. The corresponding optimum value of volumetric shrinkage V_s = 4.964 % had been evaluated using mold flow adviser [6].

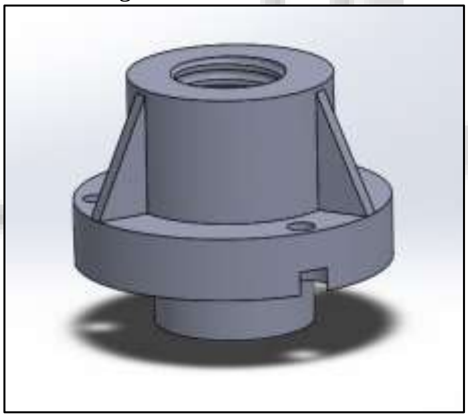

Fig. 1: Wax pattern model

A. *Wax Material*

In this study, selected material is Cerita wax F30-75 [6]. Certia F30-75 is a lightly filled pattern wax and also has excellent dimensional stability and flow characteristics. Some properties of cerita F30-75 wax are follows:

- Low ash generation on burning
- Dimensional stability
- Excellent flow
- Good injection ability
- Good interaction with ceramic cores
- Good surface appearance

Experimental data of cerita F30-75 based on thermo-physical and thermo-chemical properties are melt temperature range (60-66ºC), latent heat (70-90 J/g), thermal diffusivity (11.4×10^{-8} m^2/s), density of melt (0.955 g/cm^3) and solid density (0.846 g/cm^3) [5].

B. *Method*

This study includes Teaching Learning Based Optimization Method for optimization of process parameters. Process parameters and their levels are given on Table I.

Process parameters	Levels		
	L_1	L_2	L_3
Mold temperature (T_m)	10	15	20
Injection temperature (T_i)	60	70	80
Injection time (t_i)	5	10	15
Cooling time (t_c)	20	25	30

Table 1: Process Parameters and Their Levels [6]

Regression analysis has been done using Minitab 18.1 based on calculated values of volumetric shrinkage using taguchi orthogonal Array L_9 shown in Table II, to determine the mathematical relationship between volumetric shrinkage and process parameters.

Analysis	Process parameters				Volumetric Shrinkage (%)
	T_m(ºC)	T_i (ºC)	t_i (s)	t_c (s)	
1	10	60	5	20	4.991
2	10	70	10	25	5.807
3	10	80	15	30	6.538
4	15	60	10	30	5.003
5	15	70	15	20	5.811
6	15	80	5	25	6.651
7	20	60	15	25	5.022
8	20	70	5	30	5.970
9	20	80	10	20	6.604

Table 2: Values of Volumetric Shrinkage [6]

The regression equation is as follows:

$$V_s (\%) = 0.112 + 0.00867(T_m) + 0.07962(T_i) - 0.00803(t_i) + 0.0350 (t_c) \quad (3.1)$$

The above equation shows empirical relationship between volumetric shrinkage and independent variables such as mold temperature (T_m), injection temperature (T_i), injection time (t_i) and cooling time (t_c). To manifest the working of TLBO algorithm a constrained function of volumetric shrinkage has been considered. The objective function is to find out the optimum combination of process parameter to minimize volumetric shrinkage V_s (%).

Minimize,

$$V_s (\%) = 0.112 + 0.00867(T_m) + 0.07962(T_i) - 0.00803(t_i) + 0.0350 (t_c)$$

Range of variables:
$10 \leq T_m \leq 20$
$60 \leq T_i \leq 80$
$5 \leq t_i \leq 15$
$20 \leq t_c \leq 30$

A population size of six has been considered. The initial population has been taken arbitrarily within the range of variables and the proportionate values of the objective function.

Population	T_m	T_i	t_i	t_c	V_s (%)
1	10	60	5	20	5.00575
2	12	64	7	22	5.33251
3	14	68	9	24	5.65927

4	16	72	11	26	5.98603
5	18	76	13	28	6.31279
6	20	80	15	30	6.63955

Table 3: Initial Population

Calculations for teacher phase and learner phase has been performed up to six iterations. The obtained learner phase after the six iterations is follows.

T_m	T_i	t_i	t_c	V_s (%)
10	60	13.748	20.026	4.93559
10	60	13.747	20.014	4.93556
10	60	15	20	4.92545
10.634	60	13.747	21.128	4.94490
10.627	60.55	13.747	21.232	4.98905
10.95	60.69	13.747	22.555	5.00762

Table 4: Learner Phase (6th Iteration)

IV. Results & Confirmation Analysis

After the completion of six iterations the optimum combination of the process parameters has been evaluated, for minimum volumetric shrinkage of wax pattern is mold temperature 10 ºC, injection temperature 60 ºC, injection time 15 seconds, cooling time 20 seconds. The corresponding optimum value of volumetric shrinkage Vs = 4.92545 % is calculated by using regression equation (3.1).

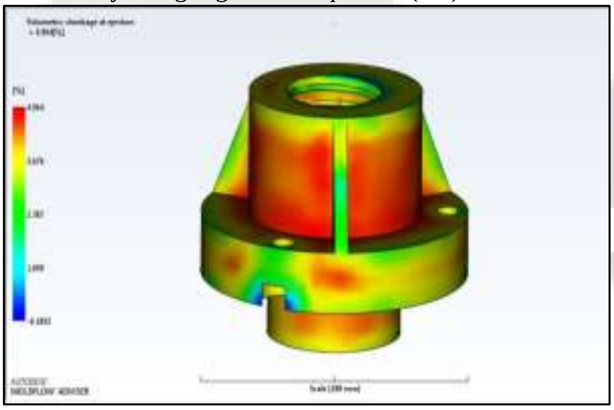

Fig. 2: Optimum Volumetric shrinkage at ejection

The confirmation analysis has been conducted in MoldFlow simulation software with optimum set of process parameters. The obtained value of volumetric shrinkage using Mold-flow adviser 2016 is V_s = 4.964 %. It is noted that the obtained results from TLBO approach are as same as the results in [6].

V. Conclusion

This paper has presented an application of Teaching-Learning-Based Optimization technique in the optimization of process parameters of wax pattern in investment casting. The following conclusions can be drawn based on the results from this study.

- TLBO method is suitable to analysis of volumetric shrinkage of wax pattern as described in this study.
- The predicted optimum value of volumetric shrinkage at ejection is V_s = 4.964 % from MoldFlow analysis.
- The result obtained from TLBO method is accurate and effective.
- Result from [6] has been validated by using TLBO Method.

References

[1] Rao R.V., Savsani V.J., Vakharia D.P. (2011a); "Teaching–learning-based optimization: A novel method for constrained mechanical design optimization problems." Computer aided design 43 303-315
[2] R.V. Rao , V.J. Savsani, D.P. Vakharia (2011b). "Teaching–Learning-Based Optimization: An optimization method for continuous non-linear large scale problems".
[3] R. Venkata Rao* and Vivek Patel (2012),"An elitist teaching-learning-based optimization algorithm for solving complex constrained optimization problems".
[4] R.V. Rao(2015), "Teaching Learning Based Optimization Algorithm".
[5] Rahmati S., REZAEI Mohamad Reza, Akbari J (2009); "Design and Manufacture of a Wax Injection Tool for Investment Casting Using Rapid Tooling" Tsinghua Science and Technology ISN 1007-0214 18/38 pp108-115 volume 14
[6] Varun Kumar, Santosh Kumar Mishra, Yogesh Kumar (2019), "An Application Of Taguchi Method In The Optimization Of Process Parameters To Minimize Volumetric Shrinkage Of Wax Pattern In Investment Casting, Jac- A Journal Of Composite Theory, Volume Xii Issue Xii, December 2019
[7] Help Documentation of "Autodesk simulation MoldFlow Adviser Ultimate 2016" Software
[8] Minitab User manual Release 18.1