DEARBORN

COLLEGE OF ENGINEERING
& COMPUTER SCIENCE

Project 1 –Linear Programming

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Group Z

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Background

Aluminium is a significant and widely used metal in manufacturing industries. Sand casting is a manufacturing process in which liquid material is poured into a mold. This mold contains a hollow cavity of the desired shape and then allowed to solidify. The solidified part is known as casting. Pictorial view is presented in figure 1 shown below.

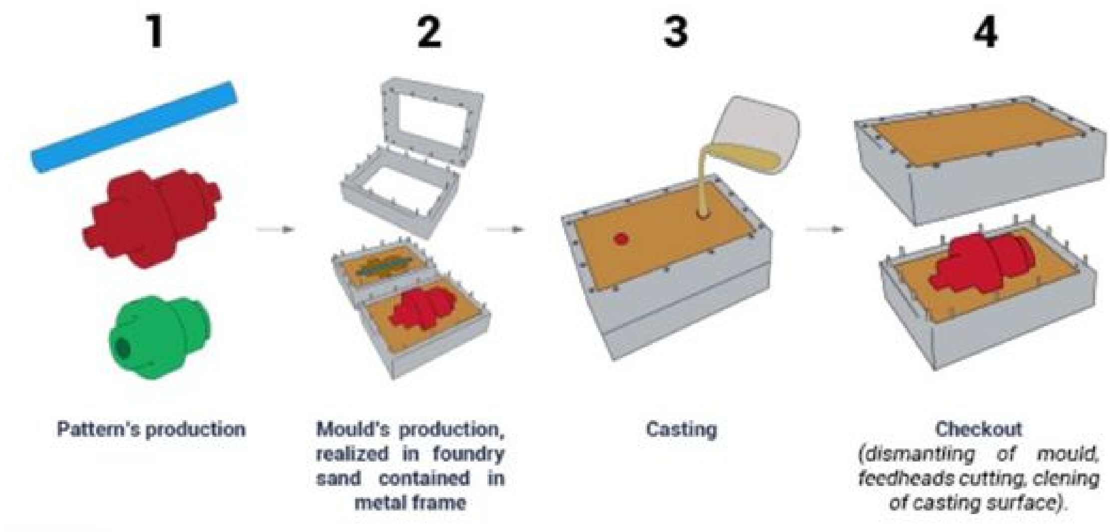


Figure1 : Casting Process

The effectiveness of the casting process depends on various parameters such as solidification time, impact strength, hardness, mold temperature, pouring temperature, runner size, desired shape, etc. To achieve full economic and technical potential, the process has to be run with optimum parameters. Hence, the selection of appropriate values of parameters plays an important role in the casting process.

Problem Statement

The aim of this paper is to adapt the Dantzig's Simplex numerical method to investigate the optimization of sand casting parameters for optimum service performance. It involved the following task items. Aluminium alloy samples were cast, machined and subjected to a series of mechanical tests. Data was collected regarding these parameters. From the body of data collected, linear functions and constraint equations were formulated and employed in the Dantzig's Simplex method for optimization of process parameters. The results showed that the Simplex method can be adapted for studying performance optimization of castings.

Objectives

- ❑ To understand the outline of the casting process and how to select the key parameters and its pattern material.
- ❑ To gather the data and carrying out the experiment by using “Simplex Numerical Method”.
- ❑ Develop a Linear Programming Model (LP Model) to obtain an optimal solution and to investigate the optimization of some sand casting parameters for improved service performance.

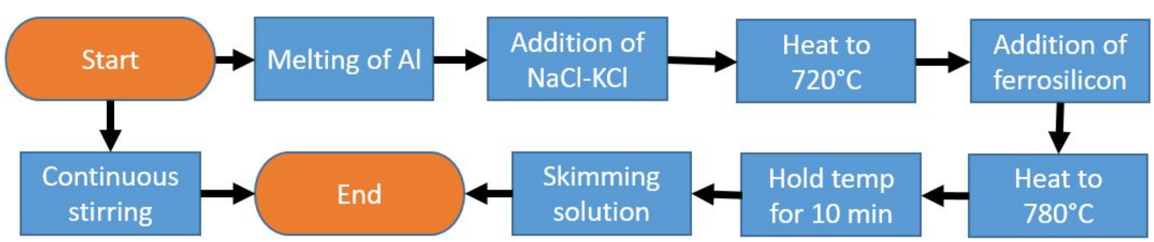
Assumptions

- ❑ The basic assumption underlying the “Linear Programming” is that any changes in the constraint inequalities will have a proportional change in the objective function.
- ❑ There are five casting parameters (Solidification time, Impact Strength Ultimate tensile strength, Hardness and Percentage Elongation) on three variables (mound temperature, pouring temperature and runner size)
- ❑ A decrease in Solidification time results in finer microstructure leading to improve the entire range of mechanical properties.
- ❑ This work mainly aims to minimize its deviation from the Ideal value.
- ❑ Possible Outcomes :
  Casting defects can be decreased by selecting appropriate parameters.

Data Collection and Validation

The data collected for the study began with the careful preparation of the aluminum melt to be used for the cast specimen. This process consisted of melting aluminum cables, adding salt mixture, heating melt to 720°C, the addition of ferrosilicon and heating the melt to 780°C for 10 min before skimming. It is important to mention that the melt was continuously stirred to ensure the equal distribution of the alloy elements throughout the solution. This process is summarized in Figure 2.

Figure 2 - Al Melt Preparation Procedure



Afterward, a similar but more complex procedure was used to cast the specimens that would undergo a tensile, impact and hardness tests. This process consisted of the variance of three key independent variables; mold preheats temperature, running size and pouring temperature. This process is summarized in Figure 3 and Table 1 below.

Figure 3: Specimen Casting

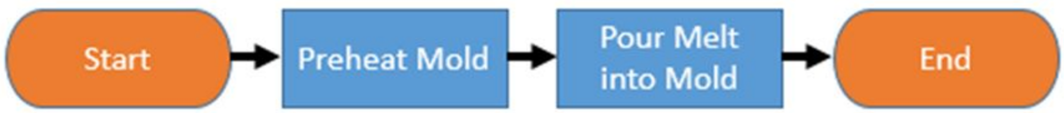


Table 1: Cast Parameters per Batch

	Preheat Temp (°C)	Runner Size (mm2)	Pouring Temp (°C)
Batch 1	**25**	100	700
	150	100	700
	190	100	700
	230	100	700
Batch 2	25	**100**	100
	25	**180**	100
	25	**285**	100
	25	**315**	100
Batch 3	25	100	**700**
	25	100	**750**
	25	100	**800**
	25	100	**850**

Finally, the specimens underwent three major mechanical tests that measured impact strength, ΔI; ultimate tensile strength, ΔU; hardness, ΔH; and percentage elongation, ΔP. The results can be seen in the appendix under table 1, 2 and 3. Machine measurements were used for all impact, tensile and hardness test. Unfortunately, the procedure to measure percent elongation was not specified. However, the paper clarified that it was deduced from the tensile test with the following equation; final length-original length)/original length * 100%.

LP Model and Solution

After the data was gathered and processed, the following LP model was constructed using the following objective function and constraint equations.

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Objective Function:

$$\Delta S = -0.005\Delta r - 0.002\Delta m + 0.013\Delta p$$

Constraints equations:

$$\Delta U = -0.048\Delta r + 0.196\Delta m + 0.166\Delta p$$

$$\Delta H = -0.031\Delta r + 0.033\Delta m + 0.021\Delta p$$

$$\Delta P = -0.006\Delta r + 0.015\Delta m + 0.057\Delta p$$

$$\Delta I = -0.001\Delta r + 0.001\Delta m + 0.001\Delta p$$

Where ΔS = solidification time, ΔI = impact strength, ΔU = ultimate tensile strength, ΔH = hardness, ΔP = percentage elongation, Δr = runner size, Δm = mold temperature, Δp = pouring temperature.

Next, the simplex method was used to determine the optimal solution to the LP model with the goal to minimize the solidification time (ΔS) and maintain the desired material properties (ΔI, ΔU, ΔH, ΔP) above the numerical value of 5. This process is laid out in a 6 step solution described below.

Step 1: Rewrite the **objective function** and **constraints equations** as inequalities.

$$0.005\Delta r + 0.002\Delta m - 0.013\Delta p - \Delta s = 0$$

$$-0.048\Delta r - 0.196\Delta m + 0.166\Delta p \le 5$$

$$-0.031\Delta r - 0.033\Delta m + 0.021\Delta p \le 5$$

$$-0.006\Delta r - 0.015\Delta m + 0.057\Delta p \le 5$$

$$-0.001\Delta r - 0.001\Delta m + 0.001\Delta p \le 5$$

Step 2: Create a table placing the objective function at the bottom.

−0.048	0.196	**0.166**	1	0	0	0	0	5
−0.031	0.033	0.021	0	1	0	0	0	5
−0.006	−0.015	0.057	0	0	1	0	0	5
−0.001	−0.001	−0.001	0	0	0	1	0	5
0.005	0.002	**−0.013**	0	0	0	0	1	0

Step 3: Identify the **most negative number** in row 5. This will be considered the Pivot Column and in this case, it is column 3.

Step 4: Divide RHS (Column 9) by Pivot Column (Column 3).The element on column 3 which gives the smallest ratio is tagged **pivot element**. (Pivot element is 0.166)

Step 5: Reduce the Pivot element to unity by dividing each entry of row 1 by 0.166. The row and column of R1C3 are termed **main row** and **pivot column** respectively.

−0.289	1.181	**1.000**	6.024	0.000	0.000	0.000	0.000	30.120
−0.031	0.033	0.021	0	1	0	0	0	5
−0.006	−0.015	0.057	0	0	1	0	0	5
−0.001	−0.001	−0.001	0	0	0	1	0	5
0.005	0.002	−0.013	0	0	0	0	1	0

Step 6: Apply a pivot operation to the tableau, including the bottom (objective) row. The pivot column will become a column of a new identity sub-matrix (ISM), in the new tableau. ***New element*** = old element—(corresponding element on the Main row * corresponding element on the Pivot column) . For instance:

$R5C9$ = R5C9 – (R1C9 * R5C3) = 0.000 – (30.120 * −0.013) = 0.392

Since all indicators (in the bottom row) are non-negative, it is final tableau and **0.392** is the optimal solution.

<u>Sensitivity Analysis</u>

We discover sensitivity ranges of casting parameters to minimize solidification time.

<u>Casting parameters</u>

- Pouring Temperature
- Mould temperature
- Runner Size

<u>Effects</u> of these parameters on:

- Solidification time

- Ultimate Tensile Strength
- Hardness
- Percentage Elongation
- Impact strength

Results are presented below.

1. Solidification time:

Increase in runner size and mould temperature caused a decrease in Solidification Time. While Increase in pouring temperature caused an increase in Solidification Time. Shown in Figure 4.

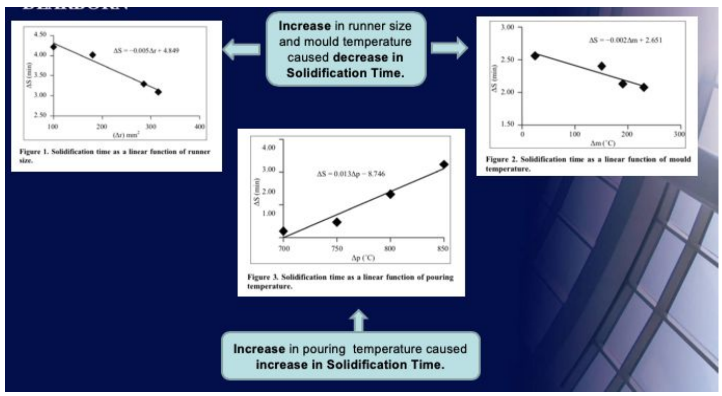
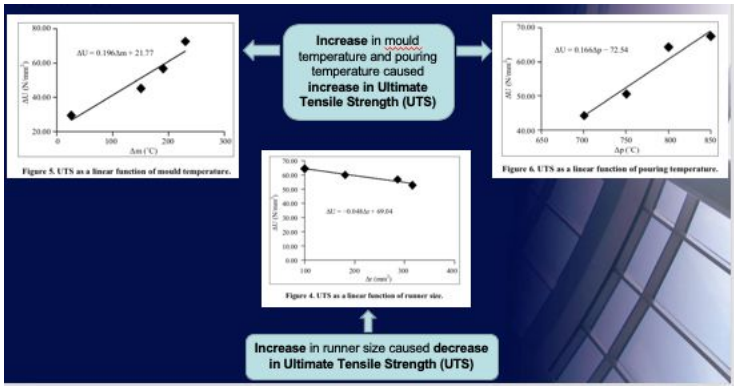


Figure 4: Correlation of Solidification time with casting parameters- pouring temperature, moulding temperature.

2. Ultimate Tensile Strength:

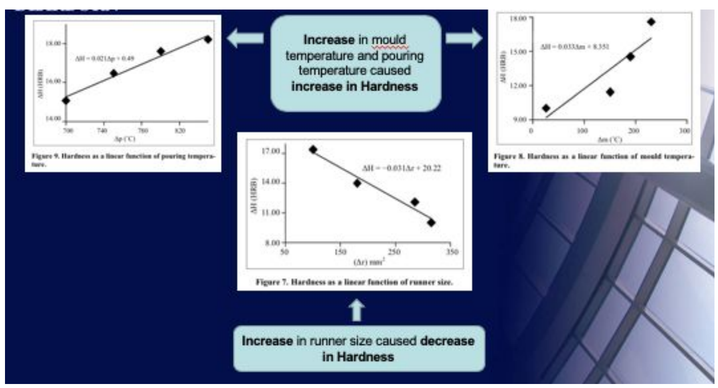
Increase in mould temperature and pouring temperature caused an increase in Ultimate Tensile Strength (UTS). While an increase in runner size caused a decrease in Ultimate Tensile Strength (UTS). Shown in Figure 5.



<u>Figure 5: Correlation of UTS time with casting parameters- pouring temperature, moulding temperature</u>

3. <u>Hardness:</u>

Increase in mould temperature and pouring temperature caused an increase in Hardness. While an increase in runner size caused a decrease in Hardness. Shown in Figure 6.



<u>Figure 6: Correlation of Hardness with casting parameters- pouring temperature, moulding temperature</u>

4. <u>Percentage Elongation:</u>

Increase in mould temperature and pouring temperature caused an increase in Percentage elongation.While an increase in runner size caused a decrease in Percentage elongation.Shown in Figure 7.

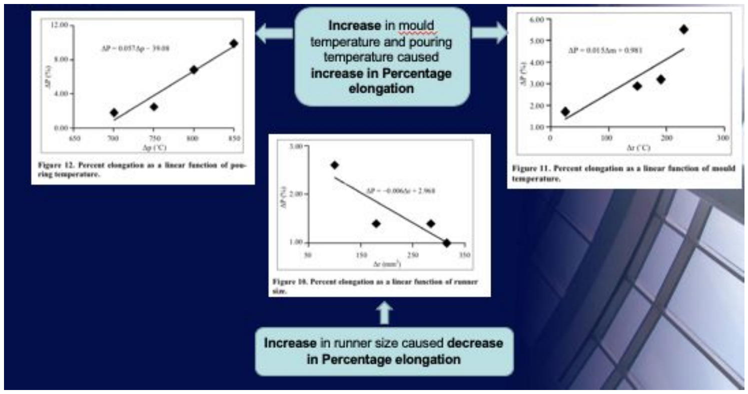


Figure 7: Correlation of Percentage elongation with casting parameters- pouring temperature, moulding temperature

5. Impact Strength:

Increase in runner size, mould temperature, and pouring temperature caused a decrease in Impact strength. Shown in Figure 8.

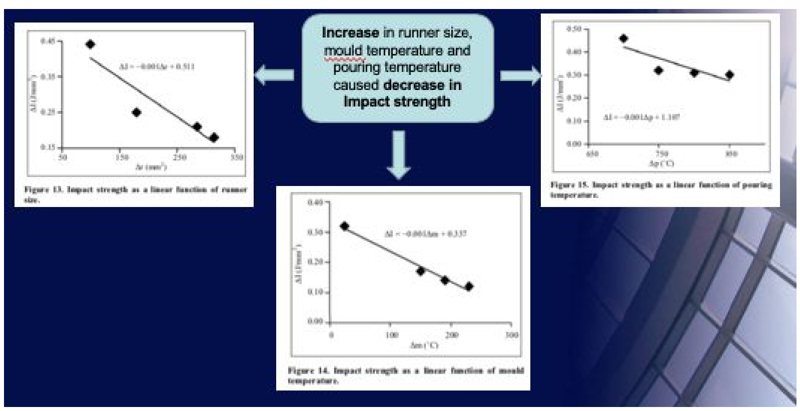


Figure 8: Correlation of Impact strength with casting parameters- pouring temperature, moulding temperature.

From the above discussion, we can state that the Diameter of runner affects the flow of molten metal, which in turn affects the rate of solidification and mechanical properties.Decrease in size of the runners lowers flow velocity. As the stream falls, velocity increases, so the runner size must be decreased to maintain the balance of the flow rate. Therefore decrease in the runner, reduces turbulence and formation of air bubbles during the solidification process. Hence this leads to fewer defects in the product.

Conclusion

In conclusion, Linear Model techniques were used to solve this real-world problem of sand casting optimization. More specifically, the simplex method was utilized to reach an optimization point of **0.392.** This shows minimum deviation (ΔS) of the solidification time (0.392) can be tolerated to achieve the optimal combination of other factors to produce a product of quality and reduce loss from defective products. The decrease in the solidification time results in the finer microstructure. Therefore we can bring improvement in the mechanical properties of the product (Oji et al).

Recommendations

One major recommendation that the team would like to propose is to keep parameters constant throughout the variety of experiments. For example, in the table below, the Pouring Temp was varied for all three batches. In comparison, the Preheat Temp was only varied for Batch 1. Keeping constant parameters throughout the batches, aside from the interesting parameter, will result in greater validity as it will reduce the unwanted effects of cross variable interaction. This was only observed in the Pouring Temp Parameter.

	Preheat Temp (°C)	Runner Size (mm2)	Pouring Temp (°C)
Batch 1	**25**	100	700
	150	100	700
	190	100	700
	230	100	700
Batch 2	25	**100**	100
	25	**180**	100
	25	**285**	100
	25	**315**	100
Batch 3	25	100	**700**
	25	100	**750**
	25	100	**800**
	25	100	**850**

Another recommendation that we would like to suggest is to use this process in plastic injection moulding based manufacturing. Since plastic injection moulding is much more sensitive to casting parameters, the Simple method can be very useful for optimization of casting parameters and improve the quality of the products (Panahi et al).

References

1. Panahi, Ali Keshavarz, et al. “Optimization of the Powder Injection Molding Process Parameters Using the Sequential Simplex Algorithm and Sensitivity Analysis.” *Journal of Manufacturing Science and Engineering*, vol. 135, no. 1, 2013, p. 011006., doi :10.1115/1.4023301.

2. Oji, John Ogheneortega, et al. “Numerical Optimization of Sand Casting Parameters Using the Dantzig’s Simplex Method.” *Journal of Minerals and Materials Characterization and Engineering*, vol. 01, no. 05, 2013, pp. 250–256., doi : 10.4236/jmmce.2013.15039.

Appendix

Table 1. Variation of casting properties with mould temperature.

Mould Temp (°C)	Solidification time (min)	Impact strength (J/mm^2)	UTS (N/mm^2)	Hardness (HRB)	Percentage elongation (%)
25	2.56	0.32	29.50	10.04	1.70
150	2.40	0.17	45.30	11.42	2.90
190	2.13	0.14	56.80	14.53	3.20
230	2.08	0.12	72.60	17.60	5.50

Table 2. Variation of casting properties with pouring temperature.

Pouring Temp (°C)	Solidification time (min)	Impact strength (J/mm^2)	UTS (N/mm^2)	Hardness (HRB)	Percentage elongation (%)
700	1.20	0.46	44.20	15.08	1.80
750	1.47	0.32	50.50	16.47	2.50
800	2.32	0.31	64.20	17.60	6.80
850	3.24	0.30	67.40	18.22	9.90

Table 3. Variation of casting properties with runner size.

Runner size (mm^2)	Solidification time (min)	Impact strength (J/mm^2)	UTS (N/mm^2)	Hardness (HRB)	Percentage elongation (%)
100	4.22	0.44	64.20	17.40	2.60
180	4.02	0.25	60.00	14.00	1.40
285	3.30	0.21	56.80	12.10	1.40
315	3.10	0.18	52.60	10.02	1.00