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Title:

Machine Learning and Optimisation to Improve Energy Utilisation

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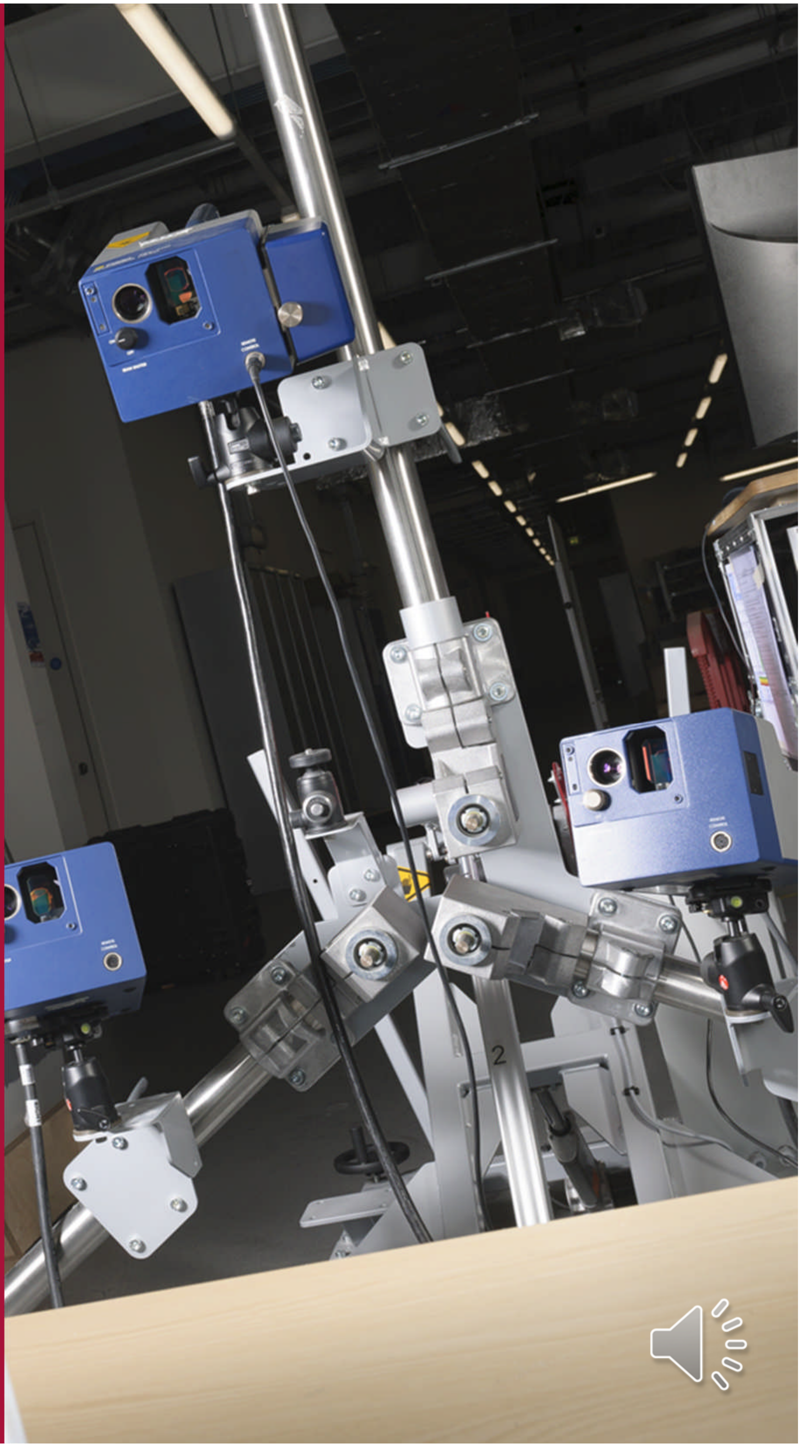


Outline of presentation

1. Introduction
2. Literature
3. Case study: Heat treatment of glass
4. Optimisation framework
5. Results
6. Conclusions

1. Introduction

- The world is moving towards a conservative approach to fulfil energy needs due to uncertainty and disruptions in the supply chain.
- Climate change, material availability, and sustainability are topics of high interest.
- Energy is a common item among all industries, and demand for it keeps increasing due to developmental activities.
- This study aims to improve energy utilization in material processing industries.
- Mining, extracting, melting, and manufacturing are typical processes in these industries, with heat treatment processes consuming significant amounts of energy.
- The work involves investigation of process industries and create a machine-learning model of the processes.
- The model will be used to build an optimization framework to achieve the best output while using the available energy.

2. Literature

- Johnson [1939], Avrami [1941] proposed analytical model of heat treatment.
- Raccuglia et al. [2016] developed data driven based classification model to predict filed and successful welds.
- Agrawal et al. [2014] [2018] have developed machine learning model to predict fatigue strength.
- Masai H et al. [2021]. Samuel B. O. et al. [2022] have developed an optimization technique using which they modelled glass material for composites of particular flexural strength using Taguchi and general regression.

3. Case study: Heat treatment of glass

- The case study is a heat treatment process of glass bottles made of soda-lime material. Material data and process details are provided by Glass technology Services UK.
- Cooling part of the heat treatment process is selected for simulation.
- The independent parameters of the process are listed in table.
- A full factorial design of experiment set is created using maximum and minimum values of independent parameters.
- This results in a data set of 27.
- ANSYS simulations are carried out to evaluate energy consumed by the process and maximum stress value in the material.

S. No	Parameters	Level 1	Level 2	Level 3
1	Annealing/Initial Temperature (^{0}C)	545	565	605
2	Cooling rate (^{0}C/min)	3	6	9
3	Exit Temperature (^{0}C)	70	110	150

Input parameters

- Annealing/Initial Temperature (^{0}C)
- Cooling rate (^{0}C/min)
- Exit Temperature (^{0}C)

Output parameters

- Energy consumption (J)
- Max Stress (von-Mises) Pa

4. Optimization framework

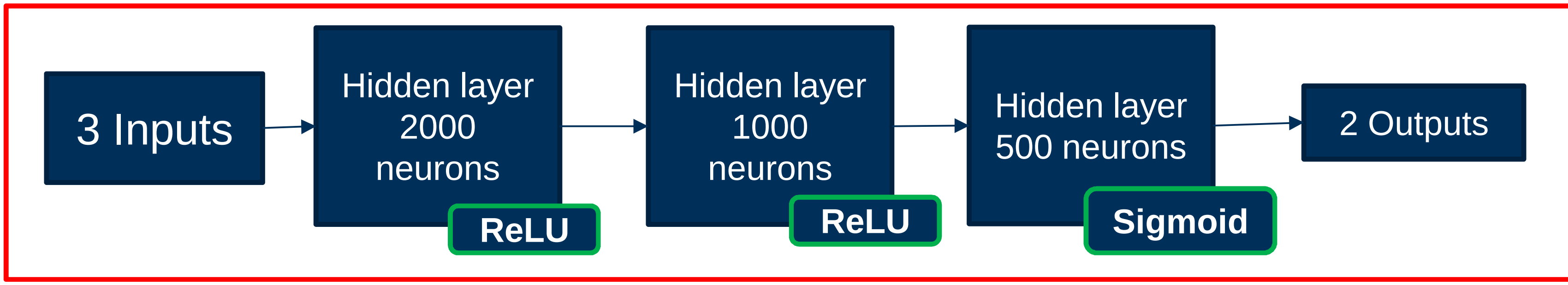
- A regression model is created using Neural Network.
- The Neural Network model is used to create objective function of Genetic Algorithm (GA).
- Genetic algorithm is developed with multi-objective and multi-criteria features.
- Using the Algorithm an optimal values of operating parameters of heat treatment are obtained for the available energy.

Main objective function:

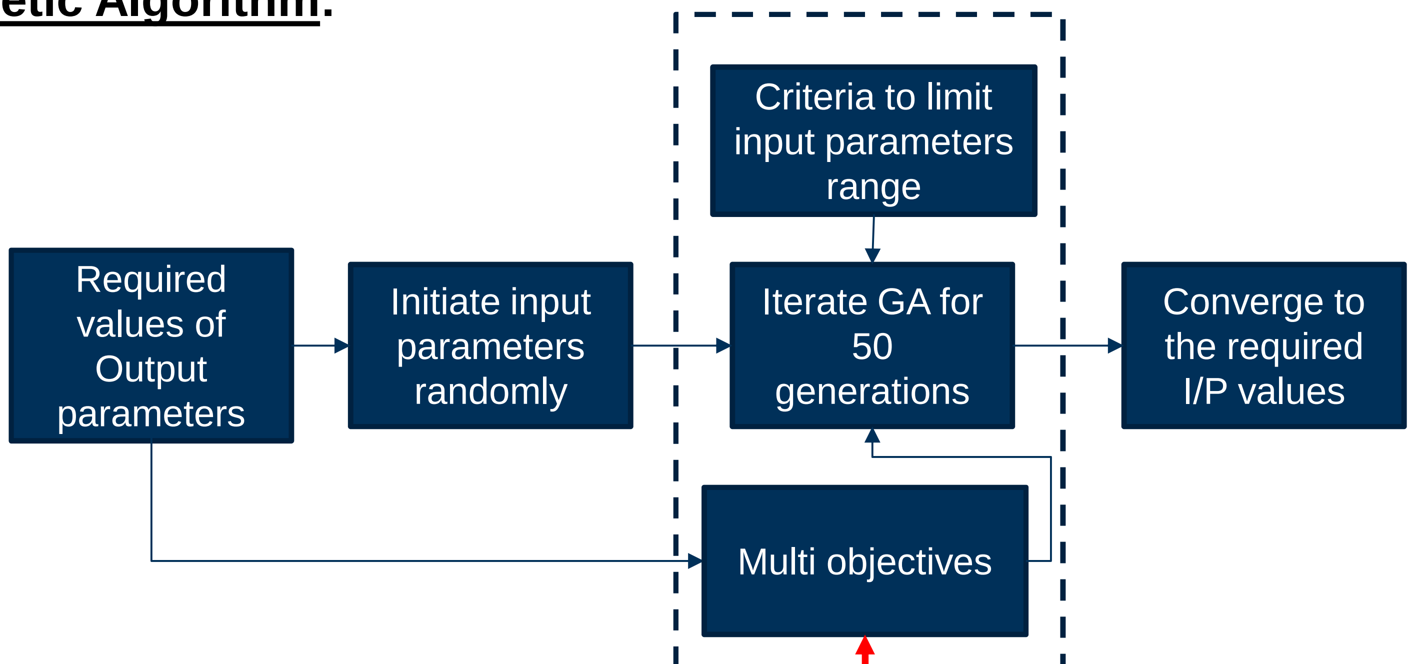
Objective function = Minimize {abs(Stress evaluated by regression model-Required stress value)+abs(Energy evaluated by regression model-Required energy value})

4. Optimization framework
Block diagram

Neural Network Architecture:



Genetic Algorithm:

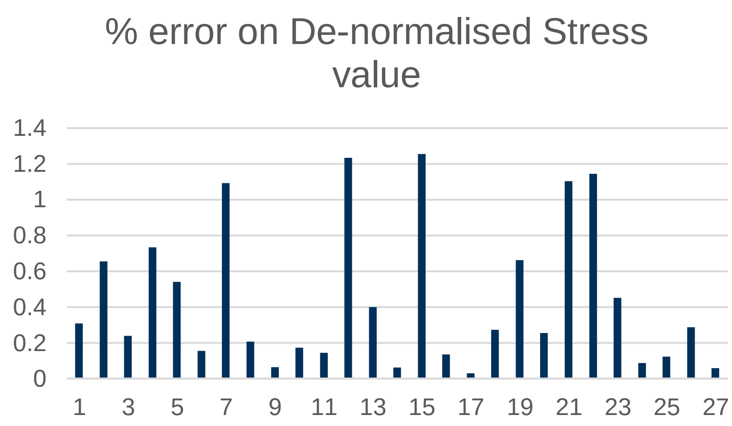


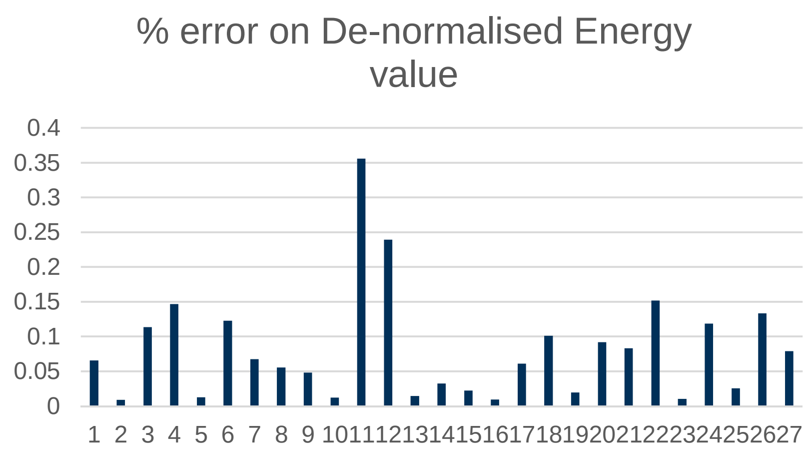
Main objective function:

4. Optimization framework

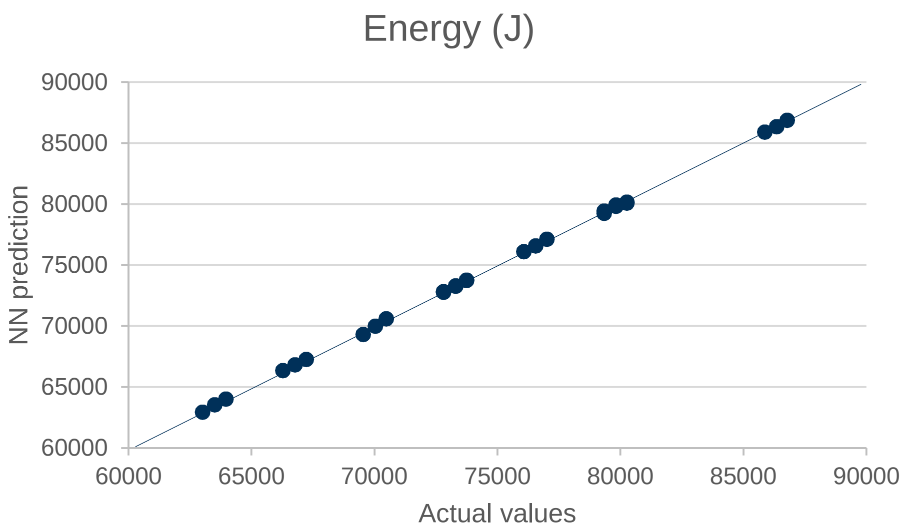
- Data is divided into 80% and 20% to train Neural Network randomly.
- 80% of the data is used for training and 20% for testing.
- Mean Squared Error(MSE) is evaluated on both training and testing. It is made sure that MSE of both data is same to avoid over-fitting.
- We noticed that approximately 50 generations in GA is enough to converge to a solution.

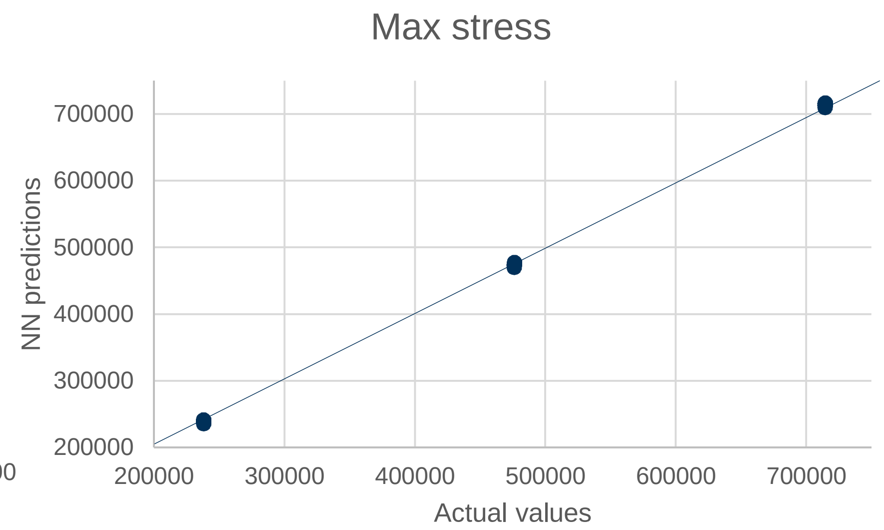
<u>Neural Network Error plots</u>





5. Results





Sample values from data

Output parameters (Simulation results)		Output parameters (Neural network Model predictions)		Percentage error	
Max Stress (von-Mises) Pa	Energy (J)	Max Stress (von-Mises) Pa	Energy (J)	Max Stress (von-Mises)	Energy
476420	73309	474945	73260.8	0.31%	0.07%
476350	76573	473229	76579.8	0.66%	0.01%
714670	63029	716380	62957.3	0.24%	0.11%
238230	70496	239977	70599.4	0.73%	0.15%
476350	86364	473776	86353.2	0.54%	0.01%

5. Results

Genetic algorithm results

S. No.	Max Stress (von-Mises) Pa (Set value)	Energy (J) (Set value)	Temp (GA result)	Exit temp (GA result)	Cooling rate(^{0}C/min) (GA result)	Max Stress (von-Mises) Pa (NN result)	Energy (J) (NN result)
1	333494	74912	593.216	130.294	4.31758	332858	74903.1
2	285847	74912	573.789	112.013	3.74986	286081	74812.2
3	285847	65405.6	548.204	143.704	3.80564	285242	65338.5
4	476435	65405.6	553.14	147.554	6.00404	476384	65379.8
5	667023	84418.4	601.384	75.5933	8.3983	666715	84426.1
6	667023	79665.2	598.011	101.057	8.36115	662141	79657.9

Set values of energy and stress values

Input parameters evaluated using Optimization framework

Values evaluated using NN

Optimization frameworks results		Set values		Percentage error	
Max Stress (von-Mises) Pa	Energy (J)	Max Stress (von-Mises) Pa	Energy (J)	Max Stress (von-Mises)	Energy
332858	74903.1	333494	74912	0.19%	0.01%
286081	74812.2	285847	74912	0.08%	0.13%
285242	65338.5	285847	65405.6	0.21%	0.10%
476384	65379.8	476435	65405.6	0.01%	0.04%
666715	84426.1	667023	84418.4	0.05%	0.01%
662141	79657.9	667023	79665.2	0.73%	0.01%

Percentage error evaluated between set values and values obtained by Optimization framework

5. Results

Utility of Optimization frame work

Initial temperature (^{0}C)	Cooling rate(^{0}C/min)	Exit temperature(^{0}C)	Max Stress (von-Mises) Pa	Energy (J)
545.971	4.80058	112.333	381141	70158.8
547.31	4.79042	113.755		
552.531	4.86698	119.288		
566.68	4.76859	132.511		
574.075	4.88605	139.3		

Fixed values

- A set of operating parameters of heat treatment can be obtained for a particular values of Energy and Max stress.
- This enables to obtain a range of input parameters from which suitable set can be chosen based on the limitations.

7. Conclusions

- The study focuses on the heat treatment process of glass to achieve desired properties while best utilising the available energy.
- Input parameter list with their maximum and minimum values is created for the study.
- An optimization framework is created by combining Neural Network and Genetic Algorithm.
- The optimization framework proposed can be applied to any industry problem, although only one case study is analysed in this work.

- At the moment. We are implementing the framework for experiments data.
- The framework is being tested for large pool of data.

Acknowledgement

This work is part of the Innovate UK funded project entitled "AI lean six-sigma process optimization for energy efficiency and waste reduction in foundation industries". We thank Innovate UK for their support

Consortium

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Glass Technology Services

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Thank you

Questions?

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