Effects of Resistance Heating Parameters on Spring Steel by using Design of Experiment

Mohd Khairul Nizam Suhaimin, Zuhriah Ebrahim, Mohd Razali Muhammad, Wan Hasrulnizzam Wan Mahmood, Massila Kamalrudin, Halimaton Hakimi

Abstract--- The resistance heating (RH) is the heating process by which the passage of an electric current through a conductor produces heat which also known as Joule Heating or Ohmic Heating. The efficiency of RH process can be affected by its parameters such as heating temperature, heating time, etc. which depends on the types of steel used. For instance, insufficient heating time and heating temperature or vice versa actually will lead to defect of spring steel when it applied resistance heating. Up to this date, there is limited study on heating temperature and heating time for RH across different types of steel. The objective of this study is to determine an ideal heating temperature and heating times that will be able to minimize the defects of spring steel products. Hence, this paper presents a study on the dimensional effect of spring steel by heating temperature and heating time through Resistance Heating concept by application of the DOE (Design of Experiment) method. By using DOE method, the heating time and heating temperature setting as independent variables were optimized. Analysis is done using ANOVA to determine the best setting of parameters to provide least dimensional defect on spring steel. Result of the experiments shows the main effect and interaction plot of ANOVA analyses, it is clear that the optimal combination of process parameters is 52 or 54 seconds for heating time and 900 degree Celsius for heating temperature and the optimal level of setting parameters that must be followed during process parameters is 54 seconds for heating time and 900 degree Celsius for heating temperature. In conclusion, result of this study provides an ideal setting of the parameter that is significant to the efficiency of Resistance Heating concept. Furthermore, the findings provide better understanding of parameter settings for Resistance Heating technique.

Keywords: Resistance heating; Heating time; Design of experiment; Spring Steel;

I. INTRODUCTION

Currently, the adaptation of resistance heating (RH) has been applied widely in the industry.Yanagimoto and Izumi (2009) stated that the heating effectiveness is led by the technology of RHby minimizing the size of heating equipment, propose an environmental-friendly heating and also provide an easier way to be operated. In heat treatment process that involveofmetal materials, the pre-heating and/or post-heating and full heating are really essential for metal bending and forming(Václav Kotlan et al, 2016). When it comes to process of metal forming and bending, RH can act as important role in term of for energy-saver because as this heating mechanism itself is classified as lower consumption of electric energy Karban et al.(2012).

Initially, the sources of RH is electricity but recently, it require precious energy source which a combination of electronic and machine so when it is used for less-precise needs such as heating which it should be used as efficiently as possible (Maki et al. , 2015). It shows that the source of resistance is versatile. Thus, RH has its own characteristics which is high-efficiency (Yanagimoto and Izumi, 2009). Generally, there are many application of resistive heating that already adapted not only just in steel and food industry but also in medical field. Number of examplehave been mentioned by Li et al. (2017) such as displays, sensors and this heating concept have been expected to be widely practiced in thermal therapy. P. Alotto et al. (2011) have applied simulation based on problems arising in electric resistance welding (ERW) processes. Although there have been various kinds of material processing which make use of resistance heating, the dominant application is more on metal-based as the heating concept is direct energizing which is more cheap and effective to be adapted (Maki et el.,2015).

One of the applications of the RH is in automotive industry which in this study, it will focus on heating of SUP9 spring steel that used for stabilizer bar. SUP9 spring steel is a high quality which is suitable for cold bending process Harada et al. (2014). The implementation of spring steel for stabilizer bar is essential as the bar itself need to be lighter and strong. But at the same time, lighter components like stabilizer bar need to be high in strength with the condition of other properties such as toughness, formability and fatigue resistance should not degrade (Podgornik et al.,2015).

Based on the latest studies, there are many works done to analyse the resistance study by using experimental approach. For example Li *et al.*, (2019), analyze the resistance heating method preference on early stage of the heat treatment process. In the study, the resistance heating does not solely focussed as the other basic stage of heat

Revised Manuscript Received on May15, 2019.

Mohd Khairul Nizam Suhaimin, Advanced Manufacturing Center, Fakulti Kejuruteraan Pembuatan, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia. (Email: khairulnizam93@gmail.com)

Zuhriah Ebrahim, Advanced Manufacturing Center, Fakulti Kejuruteraan Pembuatan, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia. (Email: zuhriah@utem.edu.my)

Mohd Razali Muhammad, Advanced Manufacturing Center, Fakulti Kejuruteraan Pembuatan, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia. (Email: mohdrazali@utem.edu.my)

Wan Hasrulnizzam Wan Mahmood, Advanced Manufacturing Center, Fakulti Kejuruteraan Pembuatan, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia. (Email: hasrulnizzam@utem.edu.my)

Massila Kamalrudin,

Halimaton Hakimi,

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

treatment also discussed which are i) Heating, ii) Quenching and iii) Tempering. The results the study discussed the correlation between the effective parameter on all the stages and the strength quality of the product which are spring steel. Yet, the work is still lacking on the analysis of the length expansion of the spring steel due to resistance heating process. Fragoudakis et al.(2014) also stated that the manufacturing process of spring steel must undergo the most crucial step which is heat treatment. Of course one of the essential stages is a heating stage. For this paper, it focuses on resistance heating.

However, despite many advantages in term of costing and efficiency for RH, there are still high rejection rates due to dimension defects. In the heating process of SUP9 spring steel, defects in dimension are responsible for high rejection rates. The dimensional defects occurred due to ununiformed heating temperature distribution, improper heating time setting, unsuitable type electrode used for holding the steel, less power supply to heat the steel (Martins et al.,2016).

Hence, it is crucial to understand the best parameter setting for specific types of steel in order to reduce dimensional defects that caused by Resistance Heating technique. Nonetheless, how the significant parameters such as heating temperature and heating time will improve the efficiency of RH that will lead to a decrease of defects to the spring steel stabilizer bar. In this regard, numbers of experiments are needed in order to determine the best parameter setting of RH for different types of steel.

Design of experiment, (DOE) methodology is an effective tool for upgrading the level of measurement and assessment. It is statistical methods that applied the use of minitab which will allow these requirements to be met in the most resource-efficient manner possible, whilst providing a greater understanding of the parameter process and highlighting opportunities for quality improvement (Krishna and Xavior, 2016).

II. REVIEW ON EFFECTIVE RESISTANCE HEATING

Table 1 presents the various definition of RH. Even though the authors described different definitions for RH, but those definitions actually share same key points which define RH is a heating method or process, which undergo the flow of current through material that hasa resistance between contacted electrodes to produces heat

Research Articles	RH Definition
Martin et al. (2017)	A way of heating for electric current to pass material's resistance, which results in increased material's temperature.
Mikno and Bartnik (2016)	A process when current flow through the heated workpiece between two contacting fixed electrodes which increase in temperature.
Silva et al. (2017)	An approach of heating that involvesof heating contacted material which behaves as an electrical resistance heater, by passing an electrical current through it.
Martins et al. (2016)	A direct contact heating that connected with a power source which producing heat by Joule's effect when the current pass through the material resistance.
Liang et al. (2014)	A heating mechanism in which when an electric current pass through a conductor and produces heat

Table 1: Definition of resistance heating

There are several significant variables or parameters that can enhance the efficiency of resistance heating effectiveness such as current and voltage supply, temperature control, electrical properties of materials, electrode set up, electric field strength and heating time. Numbers of study have discussed improvements in resistance heating whether it is indirectly or directly. For instance, it is important to apply sufficient high current for significant heat generation which makes the heating more efficient(Tan *et al.*, 2015). In this regard, the positioning of electrodes and the shape of the products might affect the current distribution (Lukas et al. 2016). The electrode should be made of conductive material for current to pass through easily (Mazur *et al.*, 2016).Maki et al. (2015) and Ogura et al. (2017) claimed that a suitable size of electrode contact area can contribute to better heating characteristic by preventing any interruption during heating. Thus, it has been suggested that cooper is the best material as an electrode for RH. In short, electrical properties of workpiece material also have affected the effectiveness of RH. For example, Thangaraju & Munisamy (2015), in his research stated that the material must have good electric conductivity in order to ensure heating is in good term.

2.1 Heating Temperature

In RH, heat will be generated by the material resistance as an amount of electrical current flow into the workpiece. Martins et al.(2016) and Annie et al., (2013) proposed that a higher heating temperature will lead to lower yield stress and tensile strength material until the desired elongation of workpiece during resistance heating. In this regard, Min et al. (2017) introduced intelligent feedforward control to improve the accuracy of temperature control. Thus, the heating temperature must be distributed uniformly in order to prevent dimensional defects at the workpiece especially spring steel (Thomasson et al. 2017). In addition, Ogura et al. (2017) implemented surfacemodification to control the heating so that heating temperature distribution is in uniform. Hence, this article presents a study of heating temperature and heating time of RH for spring steel.

Published By:
Blue Eyes Intelligence Engineering & Sciences Publication

2.2 Heating Time

The result of a literature study on RH shows that shorter heating time can improve the effectiveness of RH.Mori et al. (2013) proved that the production efficiency of gear parts had been improved drastically by reducing the heating time at RH. Wang et al.(2017) in his study explain the temperature-time curves drawn with the experimental data that describe in the initial stage of pulse current heating, the temperature of the workpiece incline rapidly. And the heating rate of workpiece can be calculated from the slope of the curve that increases with the density of pulse current going up(Didier *et al.*, 2012). With the heating time, the material's temperature increased significantly, the temperature difference between the workpiece and the surrounding environment gradually increased (S. Lupi et al., 2013). This proves that heating time affects the whole process of heating because it provides significant role towards heat loss that will stabilize the temperature. By this heating experiment, the relationship between the heating time and the stable temperature is highlighted which make it easier to be adjusted into the suitable heating setting.

III. Methodology/ Experimental

3.1 Experiment Set up

A Series of experiments are conducted involve of resistive heater machine for optimization parameter of resistance heating. The SUP9 spring steel with the dimension of 70 mm x 18 mm diameters was used as a workpiece. The workpiece was clamped on the fixture and the experimental setup is shown in figure 1. The experiments are conducted by keeping all other parameters constant. The constant parameters are the type of electrode (copper), amount of power supply and type of material used.

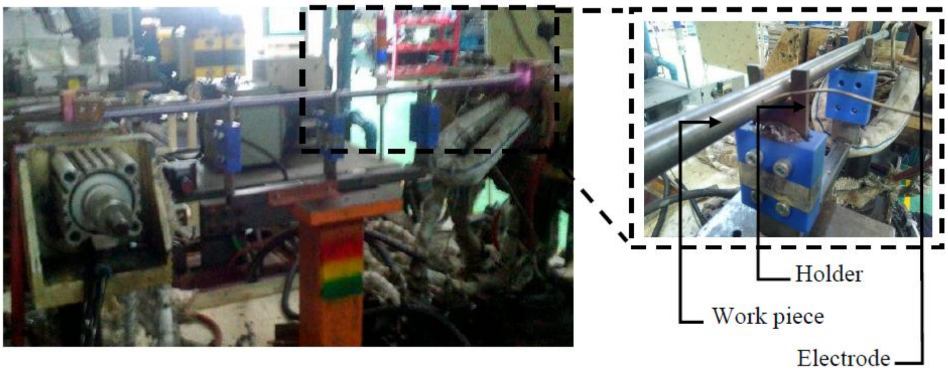

Figure 1: Experimental setup; resistive heater machine

For the experiment, 45 pieces of spring stabilizer bar with the same size and diameter are provided. The test was run according to the design of experiment plan that involvescombining two main parameters with three different level. The spring steel will be heated just like in figure 2 for a certain temperature and certain heating time that already decided for this experiment.

For each experiment, the heating undergoes for a certain heating time. The heating will stop automatically as the electrode clamp will be released after it reaches the heating temperature and heating time that had been set up before the experiment. The heating stage as can be seen in figure 2 must be carried out safely as the temperature itself is high. So, a holder used to lift up the spring steel bar after heating finished.

Figure 2: Resistance heating process of spring steel

After the heating process, the spring steel then undergoes quenching and tempering process before the measurement was taken. The defects of the spring steel dimension were clarified by using the gig design by the company based on figure 3 which the spring steel should fit the gig provided. If they cannot fit it, it means that there are dimension defects most likely because of overheating or insufficient heating occur during the heating stage.

Figure 3: Gig used to determine the final dimension of spring steel stabilizer bar

3.2 Material Selected

Spring steels are used which gives optimum strength, toughness and vibration damping. The workpiece used in this project is SUP9 spring steel of length 70mm and diameter 18mm.

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

C	SI	Mn	P	S	Cu	Cr	Fe
0.58	0.22	0.83	0.021	0.015	0.011	0.84	Bal

Table 2: Chemical Composition of SUP9 spring steel

Density (kg/m3)	Melting Point (°C)	Thermal Conductivity (W/m.K)	Coeeficient of thermal expansion (e-6/K)
7700	1450 - 1510	25	10

Table 3: Physical Properties of SUP9 spring steel

Young Modulus (Mpa)	Tensile Strength (Mpa)	Elongation (%)	Fatigue (Mpa)	Yield Strength (Mpa)
200000	650 - 880	8 – 25	275	350 - 550

Table 4: Mechanical properties of SUP9 spring steel

3.3 Data collection for a selection of parameters and response factors

ANOVA or Analysis of variance is used to test the significant difference between the parameters existed towards the output stated. There are two input controlling parameters selected with their three levels. Details of parameters and their levels used in this study which are identified for this experiment as presented in Table 1. For the purpose of this screening activity, a full factorial design was selected and the DOE plan was generated as tabulated in Table 5.

Factors	Level		
	Low	Median	High
Heating time	52	54	56
Heating Temperature	890	900	910

Table 5: Parameters (variable factors) and setting level for DOE plan

This research will be carried by nine series of the experiment. 70mm length spring steel rod with a diameter Ø 18mm with tolerance 0.5mm each) will be used as samples for the experiments. Each experiment cold bent spring steel rod that consists of five unit each;

a. Experiment Series 1 – 52 Second, 890 degree Celsius
b. Experiment Series 2 – 52 Second, 900 degree Celsius
c. Experiment Series 3 – 52 Second, 910 degree Celsius
d. Experiment Series 4 –54 Second, 890 degree Celsius
e. Experiment Series 5 – 54 Second, 900 degree Celsius
f. Experiment Series 6 – 54 Second, 910 degree Celsius
g. Experiment Series 7 – 56 Second, 890 degree Celsius
h. Experiment Series 8 – 56 Second, 900 degree Celsius
i. Experiment Series 9 – 56 Second, 910 degree Celsius

3.4 Design of experiment and data analysis

Analysis using the Taguchi method. Minitab Statistical 18 Software is used for developing the DOE plan for the workability test experimental run which are:

Process inputs: Heating time and Heating Temperature
Process output: Defects number of SUP9 spring steel

The defects of the spring steel product will be counted as they cannot fit the gig in Figure 3 which it proves that there are dimension defects. It is very difficult to predict the efficiency of resistance heating, but this effect of resistance heating affects the dimension defects of the spring steel. So, the selected response parameter/factor for this study is required efficient resistance heating to reduce dimension defects of the product. As per the Company standard, the required final products are spring steel that can fix the gig prepared as can be seen in Figure 3. If the spring steel bar cannot fit the gig prepared, they are considered defects and need reworks

IV. RESULTS& DISCUSSION

The experimental plan used in this study was generated using Minitab statistical software. Fullfactorial DOE plan was generated that consists of 45 run with a different combination of variables as tabulated in Table 5 which shows that the total defects of the SUP9 spring steel are determined for different heating time and temperature. The inspection approach is direct measurement. The components are inspected at a temperature range between 890°c to 210°c and at a heating time between 52 to 56 seconds. The responses are shown in table 5. Table 5 gives us distinct heating parameters for each experiment and the results are shown in the last column of the table. The experimental data from Table 5 were then analyzed using the Analysis of Variance (ANOVA) that is available in the Minitab. For this analysis, the main effect plot and interaction plot are selected for clarifying the relationship between the factors and the number of defects which set as responses factor and all of these factors which are set as heating time and Temperature are then used to generate the 'Main Effect Plot for Number of defects' and 'Interaction Plot for Number of defects'; refer to Figure 4 and 5 respectively.

Heating Temperature (C)	Heating Time (s)	Number of defects
890	52	3
890	54	1
890	56	2
900	52	1
900	54	1
900	56	2
910	52	3
910	54	2
910	56	4
		18

Table 6: Design of experiment plan and result

The Minitab 18 software is used for analysis based on the experimental values obtained. The design of the experiment is a significant tool for modeling and analysis of the effect of heating parameters on the defects of the product. Based on the researchers studied, heating time and temperature setting are considered as factors. The main effects plot for a number of defects is shown in figure 4. The graph plotted by taking parameter values on x-axis and response value on the y-axis. The dotted line is the main effects plot for surface roughness that indicates the mean response value. This plot will make it easier for the researcher to understand the relationship combination of both parameters in order to reduce defects and improve resistance heating.

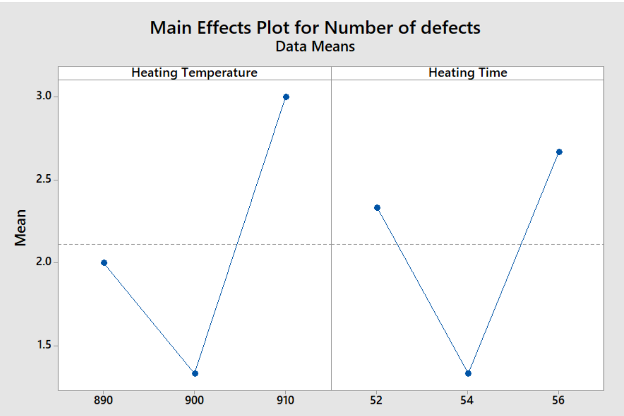

Figure 4: Main effects Plot for Number of defects

Fig. 4 shows the main effects plot for number of defects of the parameters affectingthe efficiency of resistance heating. In the case of main effects plot for number of defects, the lowest point for each factor will show the best level. It is evident from the figure that the heating temperature is greater significant parameter compare to heating time as the high temperature will provide a high inclination of the graph towards mean of defect's number. From the graph, there is a correlation between low-level heating temperature to mid-level heating temperature and mid-level temperature to high-level temperature. For parameters of heating time, there is also a correlation between low-level heating time to mid-level heating time and mid-level heating time to high-level heating time.

Similarly, interaction plot for number of defects is shown in figure 5. Interaction graphs are plotted for each combination of levels. Figure 5 shows the interaction between important parameters.

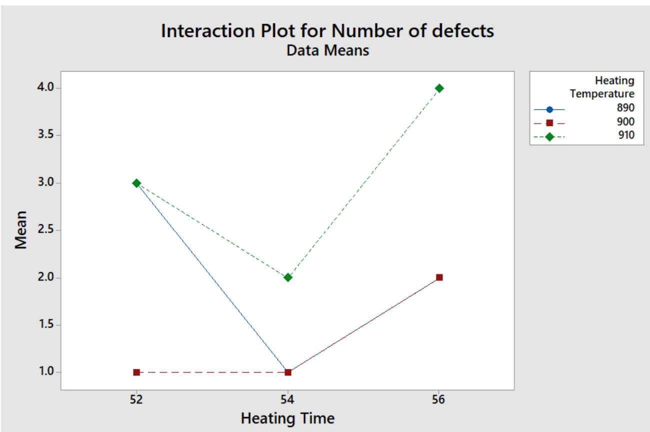

Figure 5: Interaction Plot for Number of defects

The interaction plots for number of defects in Fig. 5 indicates that there is no correlation at a low-level heating time to mid-level heating time, however, there is a inclination correlation between mid-level heating time to high-level heating time at mid-level heating temperature. There isa correlation at a low-level heating time to mid-level heating and mid-level heating time to high-level heating time at both low-level and high-level heating temperature. Based on the interaction plot, it can conclude that the best heating time should be used is 52 seconds or 54 seconds and the best heating temperature should be set up as 900 Degree Celsius. However, the best combination between both parameters setting should be implemented with 54 seconds heating time with 900 Degree Celsius.

V. CONCLUSION

As a conclusion, this paper discussed how the heating time and the heating temperature show the significant effect on the resistance heating performance, by providing minimum defects to the workpiecesused. Based on author findings from the experimental results, the following conclusions were drawn.

(1) From the main effect and interaction plot of ANOVA analyses, it is clear that the optimal combination of process parameters is 52 or 54 seconds for heating time and 900 degree Celsius for heating temperature.
(2) Among two resistance heating parameters, the heating temperature is the most significant parameter compared to heating time in order to obtain fewer defects of SUP9 spring steel stabilizer bar.
(3) The optimal level of setting parameters that must be followed during the resistance heating process in order to reduce the rejection rate due to dimensional defects are;

Heating Temperature	900 Degree Celsius
Heating Time	54 Seconds

However, for the future research, the study perhaps should be more focus on the different materials in order to compare of resistance heating process with more detail analysis. The findings in this article should contribute on comprehensive understanding of the parameter of heating time for the effectiveness of resistance heating which is important as a reference in order to be applied in the industry.

VI. ACKNOWLEDGMENT

We would like to thank Universiti Teknikal Malaysia Melaka for its support. We also would like to thank our funding; Zamalah UTeM for sponsoring the author.

REFERENCES

[1] Annie Elisabeth Jebaseeli, E. and Paramasivam, S. (2013) 'Real time temperature measurement for the thermal protection of switched reluctance machine', *International Journal of Engineering and Technology*, 5(3), pp. 2983–2987.

[2] Didier, F. *et al.* (2012) 'Mode i concrete characterization using rebar induction heating', *International Journal of Engineering and Technology*, 4(2), pp. 71–81.

[3] Fragoudakis, R. *et al.* (2014) 'The effect of heat and surface treatment on the fatigue behaviour of 56SiCr7 spring steel', *Procedia Engineering*. Elsevier B.V., 74, pp. 309–312.

[4] Harada, Y. *et al.* (2014) 'Effect of microshot peening on fatigue life of spring steel SUP9', *Procedia Engineering*. Elsevier B.V., 81(October), pp. 1493–1498.

[5] Karban, P., Mach, F. and Doležel, I. (2012) 'Hard-coupled model of local direct resistance heating of thin sheets', *Journal of Computational and Applied Mathematics*. Elsevier B.V., 236(18), pp. 4725–4731. \

[6] Krishna, V. M. and Xavior, A. M. (2016) 'Experiment and Statistical Analysis of End Milling Parameters for Al / SiC Using Response Surface Methodology', *International Journal of Engineering and Technology*, 7(6), pp. 2274–2285.

[7] Li, Y. *et al.* (2017) 'A smart, stretchable resistive heater textile', *Advance Material*, 5(1), pp. 41–46. d

[8] Liang, W. *et al.* (2014) 'Hot stamping parts with tailored properties by local resistance heating', *Procedia Engineering*. Elsevier B.V., 81(October), pp. 1731–1736.

[9] Lukas Fiala, Jan Toman, Jan Vodicka, V. R. (2016) 'Experimental Study on Electrical Properties of Steel-fibre Reinforced Concrete', *Procedia Engineering*, 151, pp. 241–248.

[10] Maki, S., Makida, Y. and Nakanishi, E. (2015) 'Power Control for Stable Achievement of Local Hardening of Steel Using Rapid Resistance Heating', *Manufacturing Science and Technology*, 3(4), pp. 128–133.

[11] Martin, E. J. *et al.* (2017) 'Gas formation in sand and clay during electrical resistance heating', *International Journal of Heat and Mass Transfer*. Pergamon, 110, pp. 855–862.

[12] Martins, J. M. P. *et al.* (2016) 'Numerical analysis of different heating systems for warm sheet metal forming', *The International Journal of Advanced Manufacturing Technology*, 83(5–8), pp. 897–909.

[13] Mazur, W. *et al.* (2016) 'Use of modified electrode caps for surface quality welds in resistance spot welding', *Journal of Manufacturing Processes*. Elsevier, 22, pp. 60–73.

[14] Mikno, Z. and Bartnik, Z. (2016) 'Heating of electrodes during spot resistance welding in FEM calculations', *Archives of Civil and Mechanical Engineering*. Elsevier, 16(1), pp. 86–100.

[15] Podgornik, B. *et al.* (2015) 'Improving properties of spring steel through nano-particles alloying', *Materials Science and Engineering A*, 638, pp. 183–189.

[16] Silva, V. L. M., Santos, L. M. N. B. F. and Silva, A. M. S. (2017) 'Ohmic Heating: An Emerging Concept in Organic Synthesis', *Chemistry - A European Journal*, 23(33), pp. 7853–7865.

[17] Tan, Y. X. *et al.* (2015) 'Heat generation and temperature rise in a resistive type superconducting fault current limiter', *2015 IEEE International Conference on Applied Superconductivity and Electromagnetic Devices (ASEMD)*, pp. 286–287.

[18] Yanagimoto, J. and Izumi, R. (2009) 'Continuous electric resistance heating-Hot forming system for high-alloy metals with poor workability', *Journal of Materials Processing Technology*, 209(6), pp. 3060–3068. doi: 10.1016/j.jmatprotec.2008.07.010.