Model Development for Casting Simulation of Railway Aluminothermic Welding

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Aluminothermic welding has been used to connect railway rails for over a century. This technique has the advantages of flexibility, weld compactness, and simplicity. External energy is not required for the procedure. Exothermic heat is produced by chemical reactions of aluminothermic elements. To create a quality welded connection, the mold and pouring system must provide uniform pouring of hot steel without turbulence, even heat dissipation or cooling, and an acceptable micro and macro structure of steel free of internal and external faults. The design of the mould was constantly changing, necessitating costly industrial experimentation. As a result, the mould's design was constantly evolving, necessitating the use of costly experimental procedures in industrial settings. The latest iteration of the model the casting cavity was improved by adding hoes in the sand and putting rails on both sides in order to more aqurately simuate heat transfer. Software programs are emulating conventional casting procedures for thermite steel casting in welded railway connections to save money and effort on costly and time-consuming industrial testing. For the 49E1 rail, NovaFlow & Solid CV were utilized to simulate casting thermite steel in the mould cavity or weld junction.

Key Words: *aluminothermic welding, simulation modeling, Novacast, welded joint*

1. INTRODUCTION

Casting simulations for traditional casting technologies are a new approach that replicates the filling of a mould with metal, as well as its hardening, and allows for the simulation of casting manufacturing. In any case, the simulation approach reduces manufacturing costs and optimizes the technical casting process [1]. Most commercial casting techniques can be mimicked, including the tremite steel casting method for aluminothermic rail welding [2]. The simulation illustrates the consequences of several inflow routes and feeding systems. Defects in castings caused by high turbulence, cold joints, shrinkage, and porosity can be avoided by enhancing the design of the input system and gas vents [3-6].

The major input data for the simulation program is a 3D CAD model for producing moulds. The casting cavity was modified in this version of the model by adding hoes in the sand and rails on both sides to more closely approximate heat flow. The program then enters the fundamental parameters of the aluminothermic process, such as thermite steel and mould properties, as well as heat transmission characteristics of the metal, sand mould, pouring temperature, and so on.

Animated representations of mould filling, thermite steel solidification, and further cooling to room temperature are included in the output data. Mould filling simulation can forecast total filling time, mould

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degradation, partial filling, and gas entrapment. Same as in our previous work the Niyama and other criteria, the temperature and cooling rate in the casting solidification simulation can be utilized to anticipate the position of shrinkage porosity [7]. Further cooling to room temperature was also modeled, to show NovaStess capabilities of the software.

The first study that was also published in Tehnika demostrated the concept of using casting simulation for railway aluminothermic welding. The model and simulation were simple it but was coupled with real experimental results like hardness along the weld and three point bending [7].

Later the model was kept the same but the simulation was developed to show the influence of preheating time on temperature distribution [8]. In this paper the model was improved by adding rails to the side and constructing the sand mould around the casting as a independent part.

Previously the sand mould was in the confines of the calculation box, but now as a separate part that space in filled with air outside mould. This aim of this study is demonstrate how the development of a proper model is crucial to casting simulation and show that its an everevolving process.

In the future, in order for the model to be closer to real conditions, the two sets of solid steel rails that are added on each side of the casting mould will be altered as heating media under the mould material category. This way, the cooling and heating temperature distribution will be improved. Finally when the cooling conditions are satisfactorily simulated to reflect real-world conditions we will apply stress and strain modelling to the weld.

Another future modification to the model could improve the preheating portion of the simulation. Because the burner is typically located about 40 cm above ground, before changing the feeder positions in future iterations of the model to accurately recreate these conditions we would move the heat source to the appropriate place or adjust the temperature, diameter, and gas accordingly at the current position.

Furthermore a new part of the model could be added to represent the divider that would be switched between air and silica sand material at the end of prehearing using the replace material function during the simulation setup phase of modelling.

2. MATERIALS AND METHODS

The steel used for simulation is comercial railway steel R260 or EN 1.0623 and the type of rails are 49E1. The chemical composition is presented in Table 1, while some other thermal characteristic are presented in Table 2.

Table 1. Chemical composition of steel that is used as an input into NovaCast database.

Element mass (%)	
C	0.54
Si	0.35
Mn	1.07
P	0.025
S	0.20
Cu	0.11
Sn	0.001
V	0.11
Al	0.31

Table 2. Thermal casting characteristics of the steel used according to the NovaCast database.

Material parameter	
Liquidus Temperature (^{o}C)	1.478.628
Euthectic temperature (^{o}C)	1.139.902
Solidus Temperature (^{o}C)	1.401.497
CLF up (%)	70.000
CLF down (%)	45.000
CLF press(%)	35.100
Q_{cr} (kJ/kg)	172.600
Q_{et} (kJ/kg)	235.711

2.1 Simulation set up

The simulation is carried out using the software program Nova Flow&Solid CV (Novacast business, Sweden) [2]. The finite volume method was utilized instead of the finite element method. The model is divided into small hexagons (cubes) and edge cells by altering the network parameters, resulting in a mathematical approximation that fully conforms to the original model. In such instance, the size of the cells is no longer as important, hence larger cells could be used (cell size 3,120, total cell count 498792. However when building the mesh the Mould thickness option was adjusted so the calculating box would start at the edge of the mould rails and bottom of sand mould. This way more realistic cooling could be achieved. Boundary condition options were left as default (normal conditions), but that is something we will consider in future upgrades to the model. The sand mould as a whole and the entire model is presented in Figure 1. As shown in Figure 2 the model consists of six elements: the rail casting (red), ingate system (blue), and feeders (green), sand mould (yellow) and rail track (grey). The one and only gating point was placed at the centre of the uppermost part of the ingate system, at the center of the blue square in Figure 2. The molten metal flow was injected in a circle of 10 mm in diameter. Gravity casting was chosen for the filling parameters with a pressure height of 300 mm, making the flow 1.149 kg/s. The overall casting mass was calculated to be 6.328 kg and the casting temperature was set at 2.200 ^{o}C. The shrinkage model was set at a high gravity influence, with a standard 83% gravity influence coefficient.

In the solver setting option, conversion, gas at filling, bubble formation, and turbulence were all taken into account for quasi-equilibrium model calculation without segregation. In all simulations, the surface heat transfer model was taken into account.

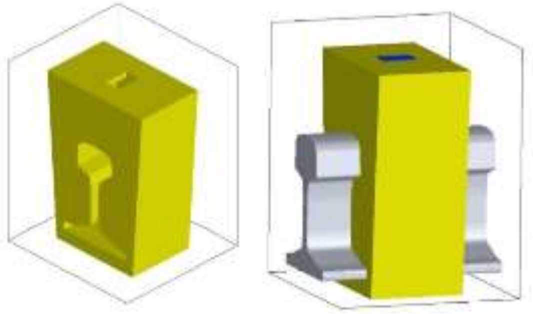


Figure 1 - Sand mould used for casting and whole casting model from an angle perspective

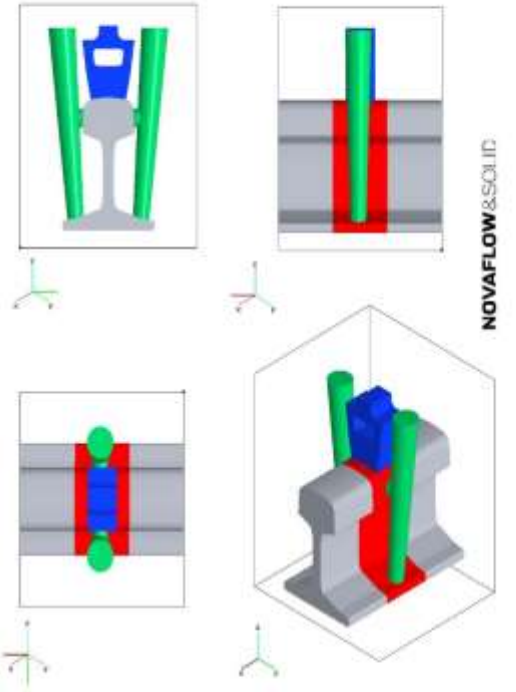


Figure 2 - Metal casting without the sand mould, from the front, side, top, and angle perspective

Simulations were conducted with the preheating option turned on. Here the mould material (silica sand) is set to the room temperature of 20 ^{o}C while the cavity medium (air) is heated with a burner (1000 ^{o}C) from the right side of the flow divider for 600 s.

The shape of the burner area is circular, 30 mm in diameter, and the flow was set at 0.1 L/s, while the initial temperature of the cavity medium was 20 ^{o}C and its flow was set at 0 L/s. These conditions were chosen in an attempt to more accurately represent realistic conditions and temperature distribution since the flow divider is not present during preheating.

3. RESULTS AND DISCUSSION

After the model was improved by adding rails to the side the asymmetry of the design (Figure 2) made an visible impact then it comes two the temperature distribution.

The is mostly visible during preheating (Figure 3) when the rail closer to the feeders is more heated then the other, since the gas doesn't flow evenly through the model. This change is then carried over to the casting stage (Figure 5) of the simulation since it takes 5.537s to fill the model to 100%. While both temperature scales for preheating and casting are given if Figure 4.

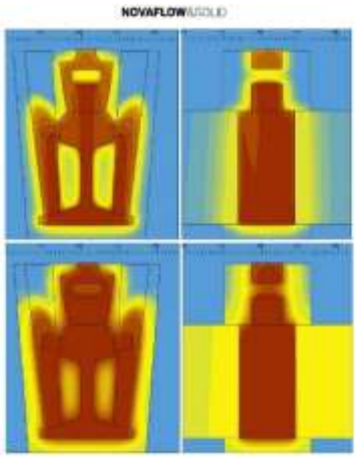


Figure 3 - Temperature distribution during prehearing after 60s, and 600s (x and y cross-section)

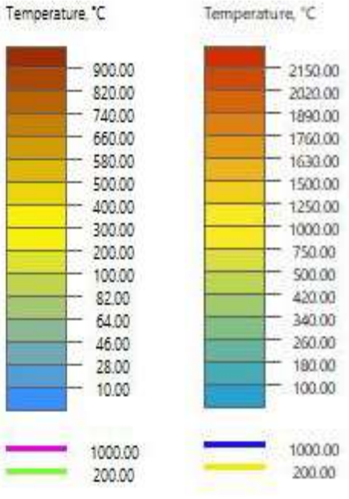


Figure 4 - Temperature scales for preheating (left) and casting (right)

As it can be seen from Figure 5 the effect of filling the mould from 30% to 90% has little influence on the temperature distribution of the rails. The influence of preheating time was established previously so just for reference the most suited preheating time was chosen from the previous study [8].

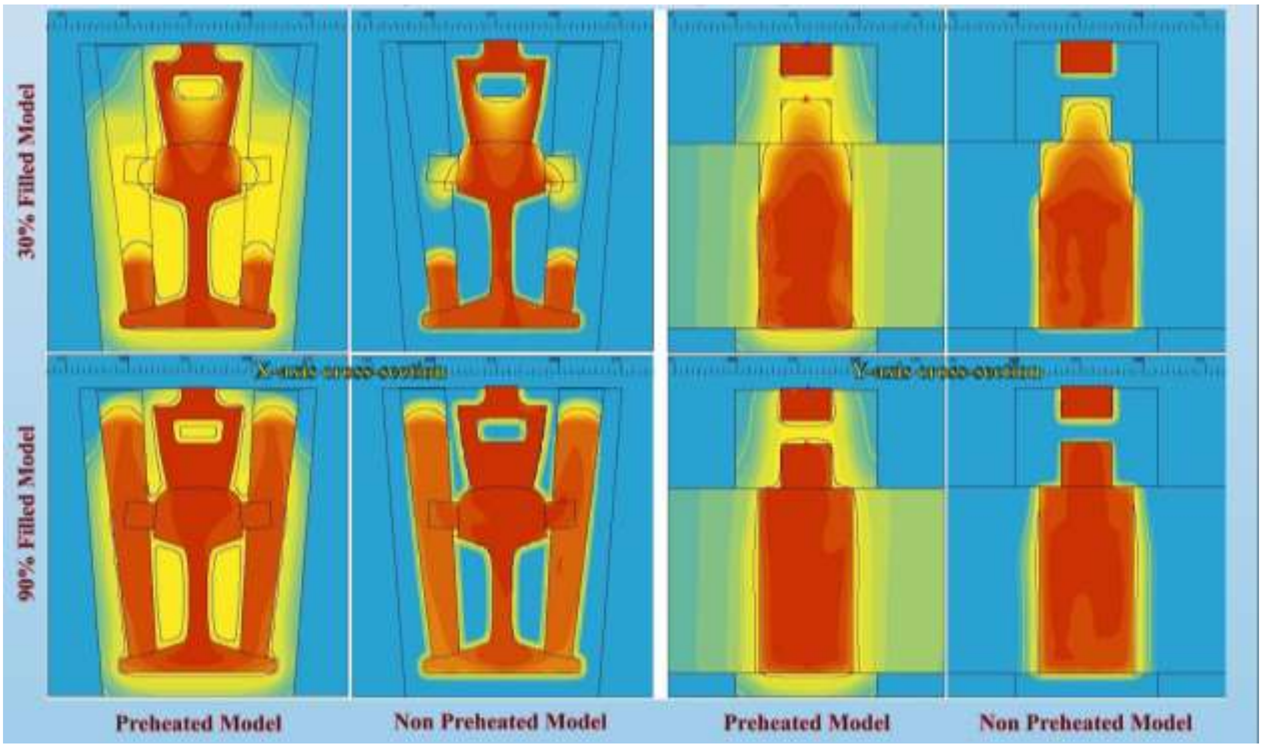


Figure 5 - Temperature distribution at 30% and 90% filled volume: preheated model and non preheated model (X and Y cross-section)

Furthermore 2D shrinkage is more pronounced in the non preheated model as was expected, however it was even more enhanced due to the influence of asymmetry as can be seen from Figure 6.

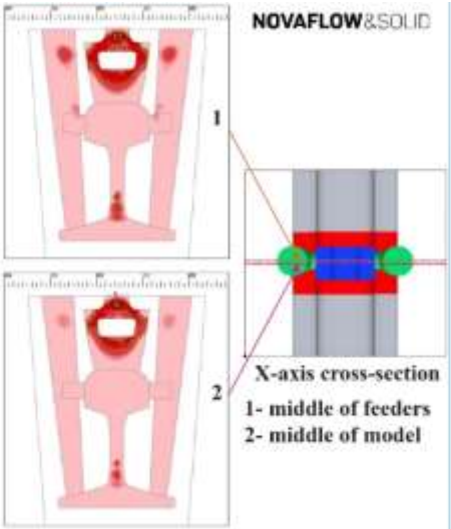


Figure 6 - Influence of asymmetry on 2D shrinkage on the non preheted model

However when it comes to the shrinkage of the preheated model as it can be seen by comparing Figures 6 and 7 again it is much less pronounce than in the non preheated one. Since the preheated model is of interest for further development the 2D shrinkage area is shown at Z cross section view coupled with relative displacement in Figure 8.

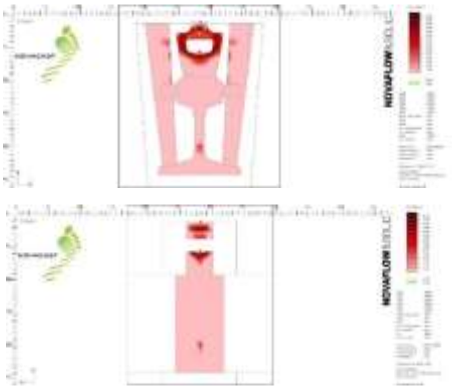
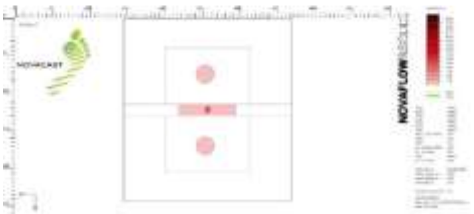


Figure 7 - 2D shrinkage of the preheated model for x and y cross-section



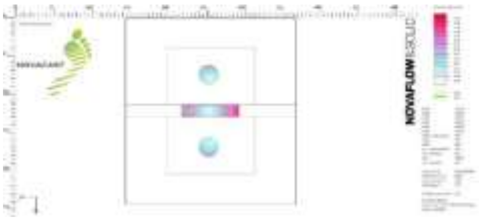


Figure 8 - 2D shrinkage widest zone and its relative displacement for Z cross-section

For future reference both principal stress and effective plastic strain at the X cross-section for the middle of the preheated model are displayed in Figure 9. They were also measured for the same Z cross-section as Figure 8 but are uniform not wouldn't illustrate much. Until we are convinced that the solidification cooling rate is somewhat realistic there isn't much sense in detailed NovaStress research. However, it will be useful in pointing out differences of model design for future iterations and upgrades.

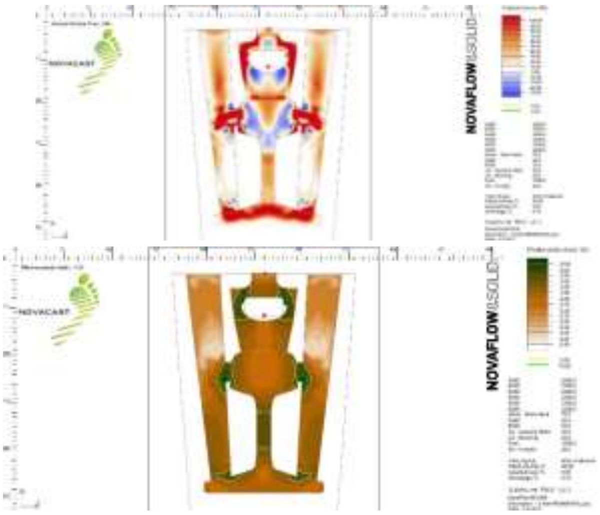


Figure 9 - Principal stress and effective plastic strain at the X cross-section for the middle of the preheated model

4. CONCLUSION

This research has shown that the aluminothermic process of rail welding can be successfully simulated using the software packages NovaFlow and Solid CV. In addition, we demonstrated how the development of proper models for simulation is crucial for adequate correlation to real-world results. Furthermore, every iteration of the model has shown to add different challenges and contribute to new ideas for future versions. The distribution of preheating temperatures has been shown to have a significant impact on shrinkage in the simulation.

The results, which were obtained with a preheating time of 600 seconds, are of interest since they are consistent with actual experience. Predicting flaws in the seam and at the contact site of the additional and base materials might also enhance the quality of welded connections. In the case of welding the type 49E1 260 rail, its applicability was demonstrated in prior work by the production of test welded joints that matched the quality requirements set by simulation in the program. Several future directions for model development were laid out, and once a satisfactory level of correlation is reached, a considerable sum of money can be saved to produce a far larger number of test-welded joints.

5. ACKNOWLEDGEMENT

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REZIME

RAZVOJ MODELA ZA SIMULACIJU LIVENJA PRI ALUMINOTERMIJSKOM ZAVARIVANJU ŠINA

Aluminotermičko zavarivanje se koristi za povezivanje železničkih šina već duže od veka. Ova tehnika ima prednosti u fleksibilnosti, kompaktnosti vara i jednostavnosti. Za postupak nije potrebna spoljna energija jer se egzotermična toplota proizvodi hemijskom reakcijom. Za stvaranje kvalitetnog spoja, kalup i sistem za ulivanje moraju obezbediti ujednačeno tečenje vrućeg čelika bez turbulencija, ravnomernu raspodelu toplote kao ujednačeno hlađenje da bi se postigli prihvatljiva mikro i makro struktura čelika bez unutrašnjih i spoljnih grešaka. Projektovanje ulivnog sistema je konstantno evoluirajući proces koji podrazumeva skupe i zahtevne industrijske probe i eksperimente. Stoga softverski programi koji simuliraju konvencionalne postupke livenja su razvijeni zarad uštede novca i napora na skupa i vremenski zahtevna industrijska testiranja. Dizajniranje modela je dinamičan proces koji stalno iziskuje napretke i dorade dok ne dostigne zabovoljavajući nivo sposoban da prikladno prikaže promene koje bi nastale pri skupim eksperimentima. Najnovija iteracija modela, šupljinu kalupa je unapredila dodavanjem rupa u pesak koje su zatvorene postavljanjem šina sa obe strane kako bi se preciznije simulirao prenos toplote i očvršćavanje. Za šinu tipa 49E1, korišćeni su NovaFlow & Solid CV da simuliraju livenje čelika aluminotermičkim putem i ovaj rad opisuje proces razvoja modela kalupa.

Ključne reči: *aluminotermno zavarivanje, simulaciono modelovanje, Novacast, zavareni spoj*