CONTINOUSLY CAST BLOOM WITH INTERNAL DEFECT - FEM MODEL OPTIMIZATION

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Abstract
Continuously cast round blooms from vanadium microalloyed steel denoted as 25CrMo4 type are very sensitive to internal defect creation during casting. Further propagation of internal cracks is affected by suboptimal heating preceding the hot rolling process. FEM offers powerful tool for simulation of the temperature gradients and stress-strain behavior. In this paper it is demonstrated that proper selection of FEM model is essential to get trustworthy results corresponding with practical observations. It is possible to find optimum between two contradictory requirements – acceptable computation time severity and trustworthy results, if the simple model is compared with experimental data and/or more sophisticated models.

Keywords: bloom, FEM, continuous casting, internal crack, stress-strain behavior, $25CrMo_4$

1 Introduction

It is generally known that niobium and vanadium microalloyed steels are very sensitive to surface and internal defect occurence after continuous casting. It was found that it is caused by suboptimal casting conditions setting such as steel superheat, casting speed, secondary cooling intensity in combination with blooms straightening in temperature range where NbC, NbN, Nb(C,N), VC, VN and V(C,N) precipitates [1-7]. It was also found that proper heating strategy preceding the hot rolling process is necessary to prevent excessive internal defects grow [8-10]. It is mandatory, to find proper heating conditions and calculate thermophysical properties of studied steel as well as to respect microstructure and chemical inhomogeneity of the continuosly cast bloom. FEM simulations are very perspective tools for studying the temperature gradients and stress-strain behaviour in the bloom [11-20]. Depending on the solved problem 2D or 3D model must be chosen. Sometimes even remeshing during FEM calculations is necessary. From the practical point of view there are two contradictory requirements. The first one is computational time limitation and the second one is the trustworthiness of the results. We used three models to demonstrate how essential is the model definition with respect to the selection of observed parameters such are equivalent of stress, equivalent of elastic, plastic and total strain.

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2 Experimental material and methods

The three different FEM simulations were performed in MSC.MARC/MENTAT software. The first simulation referred here as rough consists of 8 cells, 8346 elements and 8547 nodes. The second one labelled here as semi-rough uses 8 cells, 8841 elements and 18202 nodes. The third one considered as fine simulation works with 8 cells, 9136 elements and 27 857 nodes. In all calculations parabolic borders with internodes were used for layer m1 (crack containing layer). The heating strategy involved for continuously cast bloom with 525 mm in diameter consists of constant rating up to 1073 K for four hours, while assumed ambient temperature of the bloom was 293 K.

In these simulations was applied the heat flux (q = $2{,}5.10^4$ W/m^2 for the heating). For all simulations were used 2,5 seconds iterations. For practical problem description it is enough to use 2D model. 3D model is not necessary because the stress-strain behaviour is activated by heat gradient across the transverse cut of continuously cast bloom. Heat gradient in the longitudial direction can be neglected. From theoretical point of view the most interesting is stress-strain behaviour in the crack surrounding so the different density of elements and nodes was used for cell m1 and remaining cells m2 – m8. FEM network for both two simulations is shown in **Fig. 1**.

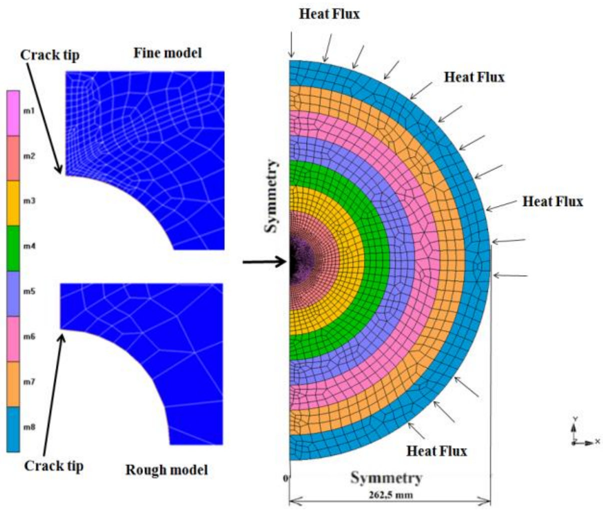

Fig. 1 Transverse half of continuously cast bloom with diameter 525 mm loaded by heat flux q. Every group of elements (m1, m2, ..., m8) is represented by specific chemical composition, mechanical and thermophysical properties. Left side of the figure represents elements meshing in crack surrounding. Meshing in crack tip surrounding for fine and rough model is also included.

Due to the known chemical inhomogenity of continuously část round blooms based on experimental procedures [1,3,8] and calculations in IDS Solidification software the yield stress, tensile stress, elastic modulus, thermal conductivity, heat capacity and thermal expansivity across the bloom diameter were modified for temperature range 273 – 1073 K. Therefore, material dependences across the bloom diameters were approximated by eight cells of materials m1, m2, ... , m8, see **Table 1** and the same procedure was performed for chemical composition **Table 2**.

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Table 1 Overview of simulated mechanical and thermophysical properties for continuously cast bloom with diameter of 525 mm.

	Yield stress (MPa)	Ultimate stress (MPa)	Modulus of elasticity (MPa)	Thermal conductivity (W.m^{-1}·K^{-1})	Specific heat (kJ.kg^{-1}.K^{-1})	Coefficient of thermal expansion (K^{-1})
Min.:	139	180	8.10^{10}	19,41	0,44	10^{-5}
Max.:	847	1100	2,5.10^{11}	40,1	0,59	2,1.10^{-5}

Table 2 Overview of chemical composition for continuously cast bloom with diameter 525 mm.

	C	Cr	Mn	Mo	V	Si	Ni	S	P
Min.:	0,22	1,12	0,7	0,2	0,04	0,2	0,3	0,008	0,008
Max.:	0,35	2,25	1,4	0,7	0,3	0,3	0,1	0,015	0,015

3 Results and discussion

Three FEM models (rough, semi-rough and fine) were used for variables calculation. Within this paper studied variables were temperatures, equivalent of stress and equivalents of elastic, plastic and total strains. The first studied variable was temperature. FEM simulations shown that elements and nodes structure doesn´t influence temperature calculation significantly (even for confidence level $\alpha = 0{,}001$). Temperature development during heating is across the bloom is characterized by heat gradient creation. The difference 70 K between bloom´s surface and the centre is achieved in early phase of heating and does not change during our simulations (data not shown).

Another studied variable was equivalent of stress. There are rather small differences among rough, semi-rough and fine model curves and all of them exhibit similar trends as it can be seen in **Fig. 2**.

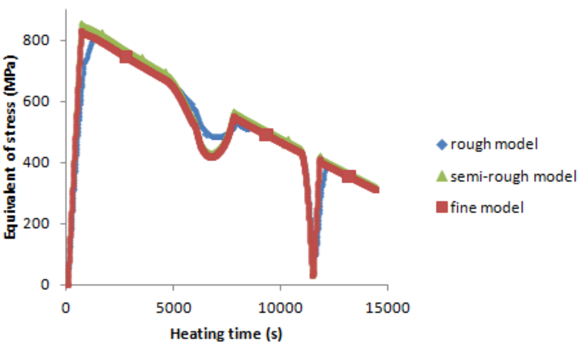

Fig. 2 Dependence of equivalent of stress on heating time for rough, semi-rough and fine FEM models.

More interesting results were achieved for the remaining three variables. Meanwhile rough model tends to overestimate equivalent of elastic strain values especially in heating time range 8200 – 10000 *s* compared to semi-rough and fine model (**Fig. 3**) however there is no statistical difference between semi-rough and fine model ($\alpha = 0{,}05$).

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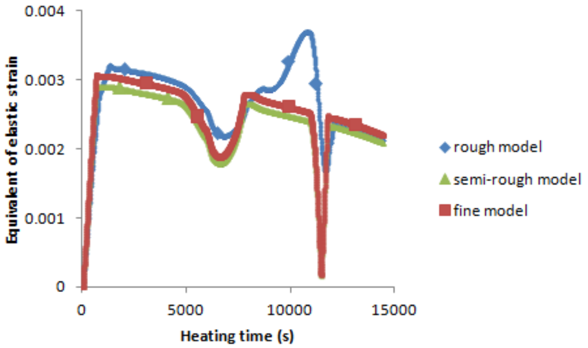

Fig. 3 Dependence of equivalent of elastic strain on heating time for rough and fine FEM simulation model.

In case of equivalent of plastic strain rough model significantly underestimates the studied variable in heating range 10000 – 14400 *s* compare to semi-rough and fine model (**Fig. 4**) meanwhile difference between semi-rough and fine model is insignificant ($\alpha = 0{,}05$).

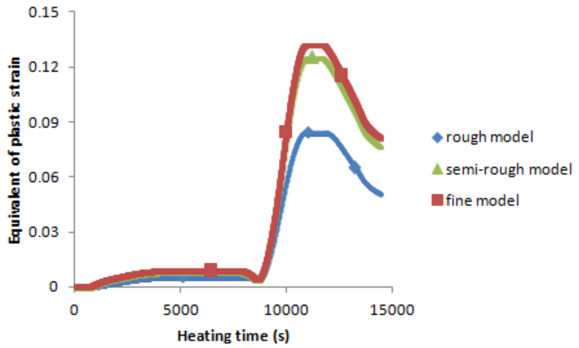

Fig. 4 Dependence of equivalent of plastic strain on heating time for rough and fine FEM simulation model.

The influence of rough, semi-rough and fine models differences expresses themselves also in case of equivalent of total strain. The curves are quite similar to those curves related to equivalent of plastic strain. It can be explained by the fact that plastic strain values are approximately one order higher then elastic strain values (**Fig. 5**).

Once again there are significant differences rough model and semi-rough and fine models. Taking into the account all four studied variables it is clear that the differences are out of acceptable range for rough model but semi-rough and fine models are very similar. For some studies and practical problems solving the simple comparison of FEM simulations output and experimental data can be used as a good tool for model acceptance. If the FEM model and experimental data fits enough it is possible to accept model as a good simplification and description of real metallurgical and material engineering problem. However in many situations not enough data are available due to many reasons. In this case it is useful to define rough model which doesn´t need enough calculation time and if the results are out of experimental data and/or expectations second model with finer structure is needed. If there is statistically significant

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difference between the models another one with even more detail structure is necessary. This procedure should be repeated until two consecutive models are statistically insignificant. Using this step by step method it is possible to archive good agreement with experiments and/or good trustworthy in case of clearly theoretical model.

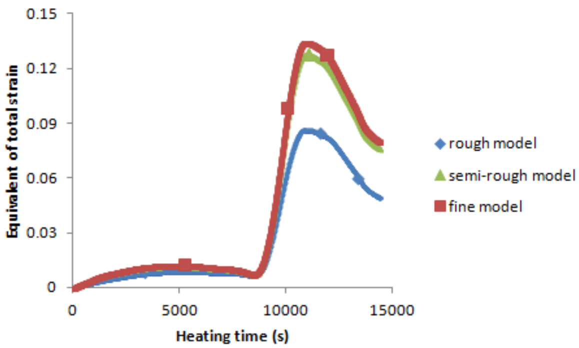

Fig. 5 Dependence of equivalent of total strain on heating time for rough, semi-rough and fine FEM models.

4 Conclusions

The main aim of this paper was demonstration of linkage between FEM model definition and the differences which may occurs during mechanical properties calculation (temperature, equivalent of stress, equivalent of elastic, plastic and total strain). The FEM calculations shown that if the model with predefined crack is used, an elements density should be chosen carefully especially in crack´s nearest surrounding. To get reliable model it is necessary to compare them with experimental results and/or to modify the model step by step until the differences between two following models are negligible.

References

[1] A. Hendrych, M. Kvíčala, V. Matolin, O. Životský, P. Jandačka: International Journal of Fracture, Vol.168, 2011, No. 2, p. 259-266, DOI 10.1007/s10704-010-9573-7
[2] J.C. Pandey, R. Manish, C.N. Choubey: Journal Failure Analysis and Prevention, Vol. 9, 2009, p. 88-96.
[3] M. Kvíčala, A. Hendrych, O. Životský, P. Jandačka: Acta Metallurgica Slovaca, Vol. 16, 2010, No. 2, p. 122-126
[4] M. Longauerová, S. Longauer, R. Mišičko: Materials Science Forum, Vols. 113-115, 1993, p. 485-490
[5] M. Longauerová, P. Bekeč, M. Fedorová, S. Longauer: Acta Metallurgica Slovaca, Vol. 17, 2011, No. 3, p. 177-185
[6] T.N. Baker: Materials Science and Technology. Vol. 25, 2009, No. 9, p. 1083-1107. DOI 10.1179/174328409X453253
[7] Y. Lu, Q. Wang, J. Li, Z. Li, S, He: Steel Research International, Vol. 83, 2012, No. 7, p. 671- 677
[8] M. Kvíčala, J. Morávka, P. Jandačka: Inżynieria Materiałowa, Vol. 178, 2010, No. 6, p. 1433- 1436

DOI 10.12776/ams.v20i1.205 p-ISSN 1335-1532
e-ISSN 1338-1156

[9] M. Kvíčala, K. Frydrýšek: *Simulation of temperature gradients and equivalent stress of low-alloyed Cr-Mo based steel*. In.: Mechanical Structures and foundation Engineering, Ostrava, ed. K. Frydrýšek, 2010, p. 54 – 61

[10] M. Kvíčala, K. Frydrýšek*: Simulation of elastic and plastic deformation behavior of low-alloyed Cr-Mo based steel*. In Mechanical Structures and Foundation Engineering, ed. K. Frydrýšek, Ostrava, 2010, p. 62-69

[11] G. V. Stepanov, V.V. Kharchenko, A.A. Kotlyarenko, A.I. Babutskii, V.N. Zhmaka: Strength of Materials, Vol. 44, 2012, No. 4, p. 429-437: DOI 10.1007/s11223-012-9397-y

[12] M.O. El-Bealy: Metallurgical and Materials Transactions B, Vol. 43, 2012, No. 3 p. 635-654. DOI 10.1007/s11663-011-9616-0

[13] Y.J. Xia, F.M. Wang, C.R. Li, J.L. Wang: Journal of Central South University, Vol. 19, 2012, p. 2403 – 2410

[14] L. Zhang, Y.M. Rong, H.F. Shen, T.Y. Huang: Journal of Materials Processing Technology, Vol. 192-193, 2007, p. 511-517

[15] D.Jing, K. Cai: Acta Metallurgica Sinica, Vol. 36, 2000, No. 4, p. 403-406

[16] K. Sorimachi, J.K. Brimacombe: Ironmaking and Steelmaking, Vol. 4, 1977, No. 4, p. 240-245

[17] Q. Liu, X. Zhang, Z. Jiang, Y. Sun, B. Shi, N. Shen: Advanced Materials Research, Vol. 418-420, 2012, p. 1698-1702. DOI 10.4028/www.scientific.net/AMR.418-420.1698

[18] Y.S., Lee, S.U. Lee, C.J. Tyne, B.D. Joo, Y.H. Moon: Journal of Materials Processing Technology Vol. 21, 2011, No. 6 p. 1136-1145. DOI 10.1016/j.jmatprotec.2011.01.017

[19] X. Wang, J. Cui, H. Zhang: Advanced Materials Research, Vol. 154-155, 2011, p. 1472-1475, DOI: 10.4028/www.scientific.net/AMR.154-155.1472

[20] R. Dautov, E. Kadyrov, E. Laitinen, A. Lapin, J. Pieska, V. Toivonen: Lobachevskij Journal of Mathematics, Vol. 13, 2004, p. 3-13

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