Patterns of changes in the plastic and deformation characteristics of rail steels alloyed with chromium in the temperature range of hot rolling

To cite this article: A A Umansky *et al* 2020 *IOP Conf. Ser.: Mater. Sci. Eng.* **866** 012015

Patterns of changes in the plastic and deformation characteristics of rail steels alloyed with chromium in the temperature range of hot rolling

A A Umansky[1], A V Golovatenko[2], A S Simachev[1] and V V Dorofeev[2]

[1]Siberian State Industrial University, 42 Kirova Street, Novokuznetsk, 654007, Russia
[2]EVRAZ Consolidated West Siberian Metallurgical Plant, 16 Kosmicheskoye Shosse, 654043, Russia

E-mail: umanskii@bk.ru

Abstract. Based on the set of experimental studies for chromium rail steels of grades E76KhF, E76KhSF and E90KhAF, the basic laws governing the influence of hot rolling temperature on ductility and the regularities of temperature and strain rate influence in the temperature range of hot rolling on plastic deformation resistance are determined and scientifically substantiated. It was shown that for E76KhF steel at deformation temperatures of 1050 °C, a sharp decrease in ductility occurs due to the presence of cementite-type carbides (Fe, Mn, Cr)$_3$C at the grain boundaries. For rail steels with a lower chromium content, the indicated ductility drop is not observed. It was established that an increase in the deformation temperature of rail steel E76KhSF causes a decrease in deformation resistance, and an increase in the strain rate significantly reduces this indicator. Also the fact that the deformation resistance decreases with distance from the surface to the central zone of continuously cast billets is established, which is due to an increase in grain size. Based on the obtained data, a new mode of rail rolling was developed in the conditions of the rail and beam workshop of EVRAZ ZSMK JSC, the introduction of which allowed the quality of the rails to be significantly improved as well as the technical and economic indicators of their production with an economic effect of approximately 120 million rubles/year.

1. Introduction

One of the trends in the development of rail rolling in Russia and the world is to increase the degree and complexity of alloying rail steels. The indicated trend was also reflected in the latest version of the state standard for the production of railway rails, which is currently in force (GOST R 51685-2013). So in this standard there are four types of rail steels alloyed with chrome in addition to vanadium (E76KhF), silicon (E76KhSF) and nitrogen (E76KhAF, E90EAAF), and in its previous version (GOST R 51685-2000) there was only one steel grade, at the same time doped with vanadium and chromium (E78KhSF).

A significant (up to 2 times) increase in the maximum permissible chromium content in such steels should also be noted. At EVRAZ ZSMK JSC, which is today the leading manufacturer of railway rails in Russia, currently E76KhF and E76KhSF steels are used as the main steels for the production of railway rails instead of previously used E76F steel.

The analysis of the literature data shows [1-5] that the theoretical justification of the optimal temperature ranges of deformation (at which the ductility has the maximum and the deformation resistance is minimal) for complex alloyed steels is significantly complicated due to the complexity and multivariance of structural changes. Moreover, this problem is exacerbated in relation to the production of rail profiles, since their complex cross-sectional shape causes a significant non-uniformity of deformations during rolling.

Thus, we can conclude that, today, the determination of the patterns of change in ductility and deformation resistance of complex alloyed rail steels of a newly mastered range of products depending on the rolling temperature is an urgent task.

2. Methods of research

In the framework of the presented work, continuously cast billets with a cross-section 300×360 mm of current meltings in the electric steel-smelting shop of EVRAZ ZSMK JSC were used as an object of research to determine the ductility and deformation resistance. Samples were taken directly from the surface of billets, as well as at a depth of 50 mm, 75 mm and 110 mm from the surface of the billets in order to obtain maximum information about the plastic and deformation characteristics of steel in various zones of continuously cast billet. It is known that continuously cast billets are characterized by a three-zone structure, which includes a near-surface cortical zone, a columnar crystal zone and a central zone. According to the actual data of the structure analysis of the studied billets, the depth of the cortical zone is about 15–25 mm, the zones of columnar crystals are 50–60 mm, the rest is the central zone. That is, samples from all three zones of non-cast-in-place blanks were used for analysis.

Plasticity studies were carried out for samples of E76KhF steel, and studies of deformation resistance were carried out for steel E76KhSF, which is conditioned by the almost similar chemical composition of these steel grades according to the requirements of GOST R 51685-2013 (differences exist only in the ranges of variation of the allowable silicon and chromium content, while the indicated ranges overlap) and minor differences in the actual chemical composition of the analyzed bottoms of the current production.

To study the ductility, the hot torsion method was used in the temperature range 900–1200 °C, and the degree of shear strain was taken as a criterion for ductility. The studies of plastic deformation resistance were carried out on the unit Gleeble System 3800 using hot settling in the temperature range 900–1150 °C at strain rates of 1 s^{-1} and 10 s^{-1}.

The metallographic studies of rail steel samples were carried out using OLYMPUS GX-51 optical microscope and TESCAN MIRA 3 LMH scanning electron microscope with a Schottky field emission cathode. Shimadzu XRD-6000 X-ray diffractometer was used to determine the phase composition.

3. Results and discussion

According to the data obtained, the ductility of the near-surface and 50-mm-thick layers of continuously cast billets of rail steel E76KhF due to the deformation temperature has a complex behavior (figure 1): at the beginning of the indicated temperature range of deformation (with an increase in temperature from 900 to 1000 °C), plasticity intensively increases, then with a further increase in temperature, a noticeable decrease occurs with a minimum value at temperatures of 1025-1050 °C, after which the ductility sharply increases, reaching maximum at 1100 °C, and at the end of the considered temperature range (1100-1200 °C) is a smooth reduction in ductility.

The obtained experimental data indicate the absence of sharp changes in the plastic properties of continuously cast billets from E90KhAF steel and the absence of plasticity drop (figure 2) recorded for E76KhF steel, which is due to a significantly lower chromium content. It can also be noted that the absolute values of ductility for steel E90KhAF are lower compared to steel E76KhF, which is primarily associated with a higher carbon content.

It should be noted that according to the results of earlier studies of the ductility of continuously cast billets of E76F rail steel [6], there was also no recorded decrease in ductility at temperatures of 1050 °C. The effect of chromium on ductility is confirmed by the results of metallographic and X-ray diffraction studies of steel samples E76KhF: cementite carbides $(Fe, Mn, Cr)_3C$ were found at grain boundaries – figure 3. These carbides do not completely dissolve in austenite at temperatures up to

1050 °C and prevent the degree of growth shear deformations, that is, in fact, reduce the ductility of steel.

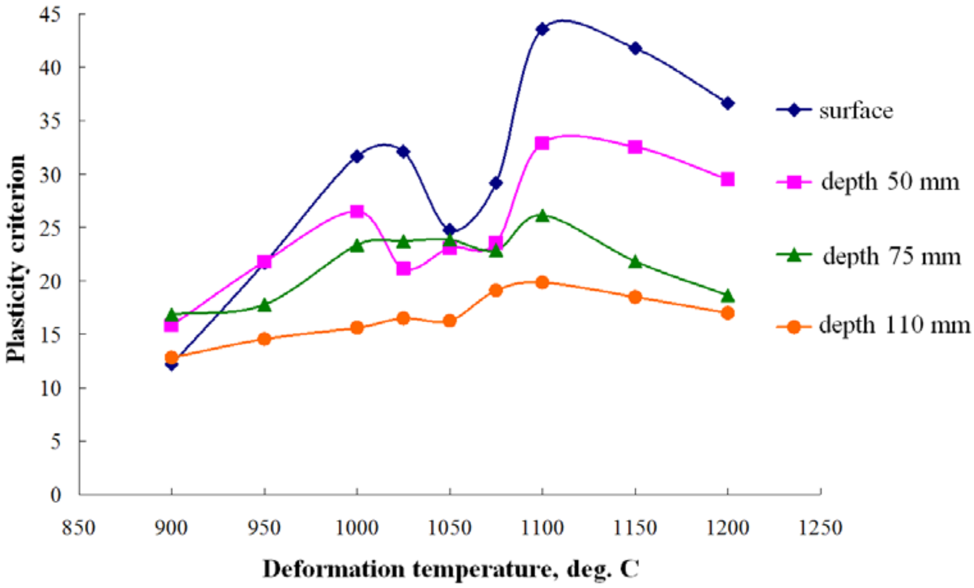


Figure 1. The ductility dependence continuously cast billets of rail steel E76KhF on the deformation temperature.

According to the research results, one can also note a general tendency for both considered steels to decrease ductility with distance from the surface to the central zone (figures 1, 2), which is due to the difference in grain size. Thus, according to the data obtained in the near-surface layer, the average grain diameter is 1.3–2.1 times smaller compared to the central zone of the billets, and there is a tendency for the increase in the difference in grain sizes and in strain temperature.

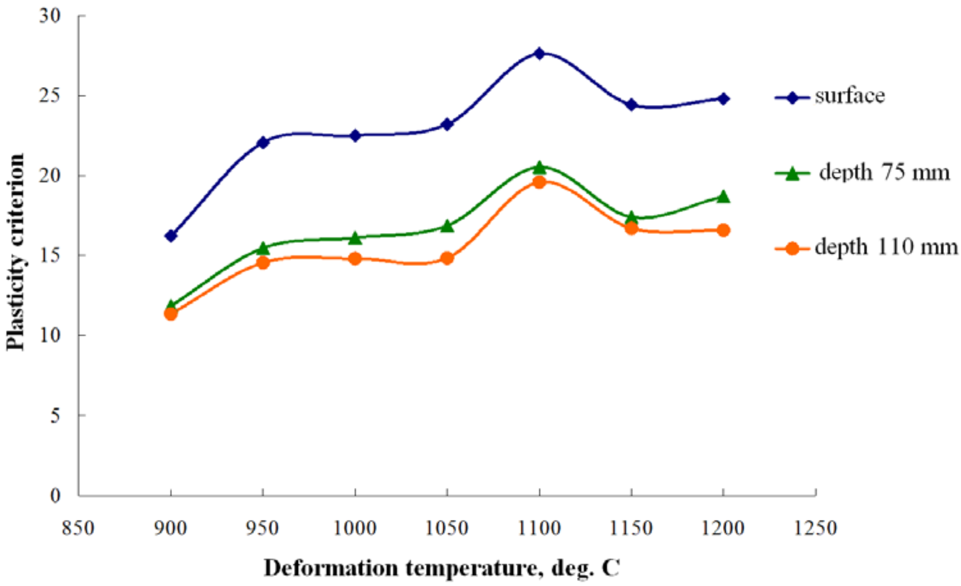
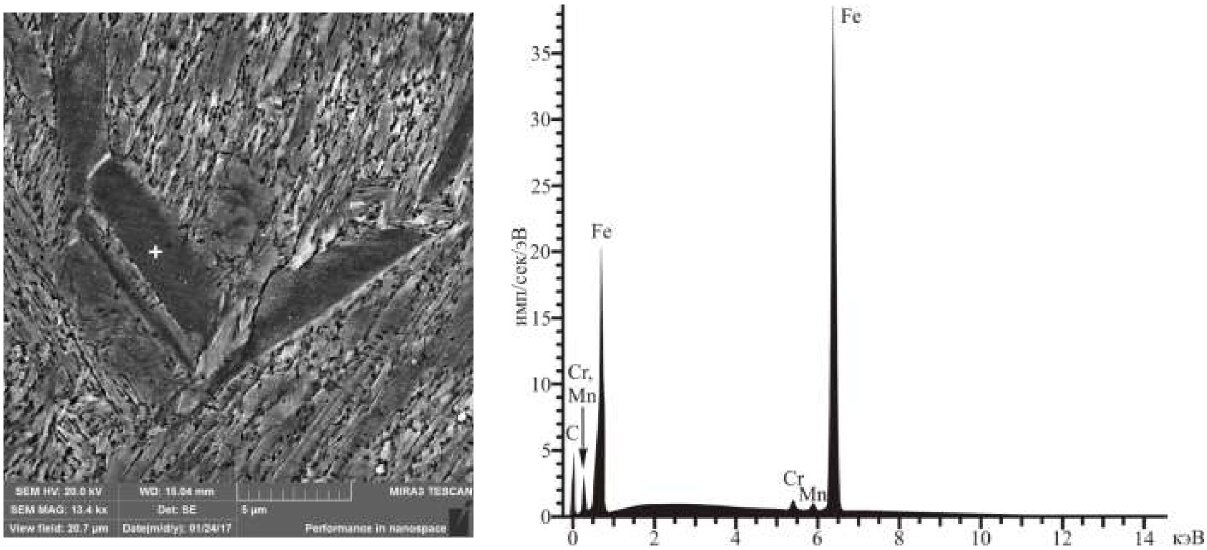


Figure 2. The ductility dependence of continuously cast billets of rail steel E90KhAF on the deformation temperature.



(a) (b)

Figure 3. Cementite carbides in steel grade E76KhF:
a – steel microstructure; b – distribution of elements in the carbide phase.

Based on studies of plastic deformation resistance, it was found that an increase in the deformation temperature of E76XSF rail steel causes a decrease in this indicator (figure 4). There is also a decrease in deformation resistance as the distance from the surface to the central zone of continuously cast billets increases, which, as shown above, is due to an increase in grain size. The significant effect of the increase in the strain rate on the increase in deformation resistance was established (figure 4), which is due to the acceleration of hardening processes, which are realized due to an increase in the density of dislocations and point defects, with an almost constant speed of the opposing softening processes [7–9].

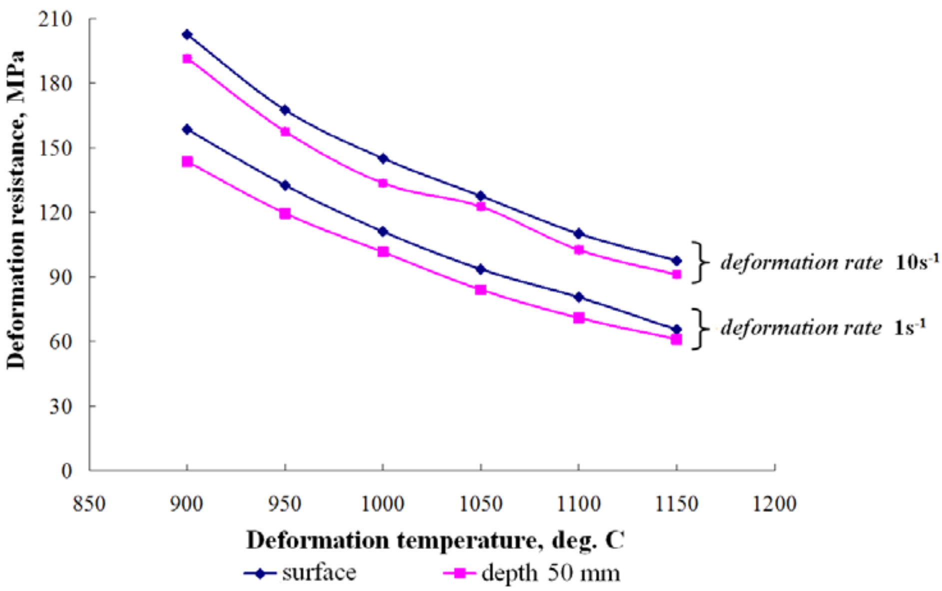


Figure 4. The deformation resistance dependence of continuously cast billets of rail steel E76KhSF on the deformation temperature.

Using the obtained experimental data on the ductility of E76HF rail steel, a new mode of rail production at the universal rail and beam mill of EVRAZ ZSMK JSC was developed, which made it possible to reduce the rejection of finished rails according to surface defects [10]. Improvement of the rails quality is achieved by redistributing the reductions between the passes in such a way that rolling in the split gauge (where the unevenness of the deformation has the greatest values) is carried out at temperatures close to the temperature of maximum ductility (1100 °C), and compression at temperatures of ductility drop (1025-1050 °C) have minimum values. To obtain the specified distribution of compression, the heating temperature of the billets for rolling was reduced from 1200 °C to 1170-1180 °C and the number of passes in the crimping stands was reduced. The limit of increase in reductions in individual passes from the point of allowable rolling force and moments on the shaft of the load engine is justified using the obtained experimental dependences of the strain resistance on temperature and strain rate.

The introduction of the developed rail production mode at the rail and beam mill of EVRAZ ZSMK JSC allowed the quality of the finished rails to be improved, and the specific energy consumption for rolling, fuel for heating billets, the specific consumption of rolling rolls to be reduced and the productivity of the mill to be improved. The total economic effect is estimated at 1250 million rubles/year.

4. Conclusion

The experimental studies established the dependences of the ductility and deformation resistance of rail steel alloyed with chromium on temperature-strain conditions. The data obtained made the theoretical basis for the development of a new mode of rail rolling, providing a significant increase in their quality and technical and economic indicators of production.

Acknowledgments

The reported study was funded by RFBR and Kemerovo region, project number 20-48-420011.

References

[1] Dimatteo A, Lovicu G, DeSanctis M and Valentini R. 2012 *Proceedings of Crack Paths* 131–139
[2] Lopez-Chipres E, Mejıa I, Maldonado C, Bedolla-Jacuinde A and Cabrera J M 2013 *Materials Science and Engineering: A* **460-461** 464–470
[3] Gladkovskii S V, Potapov A I and Lepikhin S V 2015 *Diagnostics, Resource and Mechanics of materials and structures* **4** 18–28
[4] Banks K M, Tuling A, Klinkenberg C, and Mintz B 2011 *Materials Science and Technology* **89** 537–545
[5] Konovalov A V, Smirnov A S et al 2016 *Metallurgist* **59** (11) 1118-1121
[6] Simachev A S, Temlyantsev M V and Oskolkova T N 2016 *Steel in Translation* **46** (2) 112–114
[7] Manonukul A and Dunne N 1999 *Acta Mater* **47(7)** 4339–4354
[8] Umanskii A A, Golovatenko A V and Kadykov V N 2017 *Izvestiya Ferrous Metallurgy* **60** (10**)** 804–810
[9] Umansky A A, Golovatenko A V, Kadykov V N and Dumova L V 2016 *IOP Conference Series: Materials Science and Engineering* **150** *012029*
[10] Umanskiy A A, Dorofeev V V, Golovatenko A V and Dobryanskiy A V 2018 *Cherniye Metally* **10** 38–42