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Letter to the Editors

Modification of microstructure and the alligatoring damage in a modified 9Cr–1Mo steel

R. Kishore *, T.K. Sinha

Materials Science Division, Bhabha Atomic Ceramic Division, Mumbai 400 085, India

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Abstract

Alligatoring damage was encountered during the rolling of a modified 9Cr–1Mo steel in the as-received condition. The cause of this failure was attributed to the banded nature of the microstructure formed by coarse carbides, which aids the nucleation of the voids at the interface. The banded microstructure was destroyed by a heat treatment which gives a uniform fine distribution of carbides. Such a microstructure could eliminate the alligatoring problem in this steel. © 1999 Elsevier Science B.V. All rights reserved.

1. Introduction

Alligatoring is the defect encountered in hot or cold rolling practice where a flat slab or rod splits into two halves on a plane parallel to the rolling plane, located most commonly at the centre of the formed product. Polakowski [1] defined a term Δ as the ratio, mean thickness of work slab/roll contact length, which is high for a thick slab and reduces with subsequent passes for a given roll diameter. For a high value of Δ, the defects accumulate in the centre plane that is in tension and as the value of Δ becomes low, the stresses in the centre plane become compressive with respect to the surface, which is in tension. The causes a torque in the sheet, splitting it in the central plane [1].

Though the phenomenon of alligatoring has been known for many years there are no systematic attempts to relate the role of microstructure to this type of damage, especially on commercial steels. The failure of a sheet by alligatoring has also been modelled on the basis of the microstructure to originate from the void formation at the carbide–matrix interface. Recently Xu and Daehn [2] have conducted a detailed study on the nucleation of voids at carbide precipitates in a 1090 steel and proposed a model for alligatoring in the spherodised condition. They observed that intense shear at the leading edge of the slab caused cracking at the concavity and the final failure of the plate was assisted by the tensile stresses normal to the rolling plane. In the present investigation, we have encountered the alligatoring problem during cold and hot rolling of modified 9Cr–1Mo steel sheets/roads. This steel is used extensively in steam tubing and is known to possess good fabricability [4]. In this note a correlation between the microstructure and the alligatoring damage during cold rolling in this steel is discussed in the light of known models [1–3].

2. Experimental procedure

The modified 9Cr–1Mo steel was received as a hot rolled billet with square cross section of 120 × 120 and 240 mm long, the chemical composition for which is given in Table 1. The as-received (designated as AR) microstructure shows severe banding along the transverse direction of the billet (Fig. 1(a)). These bands under higher magnification could be resolved to be rows of segregated globular carbides (Fig. 1(b)). Plates of 120 × 120 and 20 mm thick sliced from this billet along the transverse plane were used in this investigation. One lot of the plates were given a 1100°C (1 h) normalising and a tempering treatment at 710°C (1 h) (designated as 710T). The normalising treatment results in complete dissolution of the carbides and the 710T microstructure

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[*] Corresponding author. Fax: +92 22 5560750.

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Table 1
The nominal composition of the steel under present investigation, %wt

Cr	Mo	C	Si	Mn	Nb	V	P	S	N (ppm)
9.5	1.0	0.1	0.5	0.35	0.08	0.21	<0.025	<0.025	350

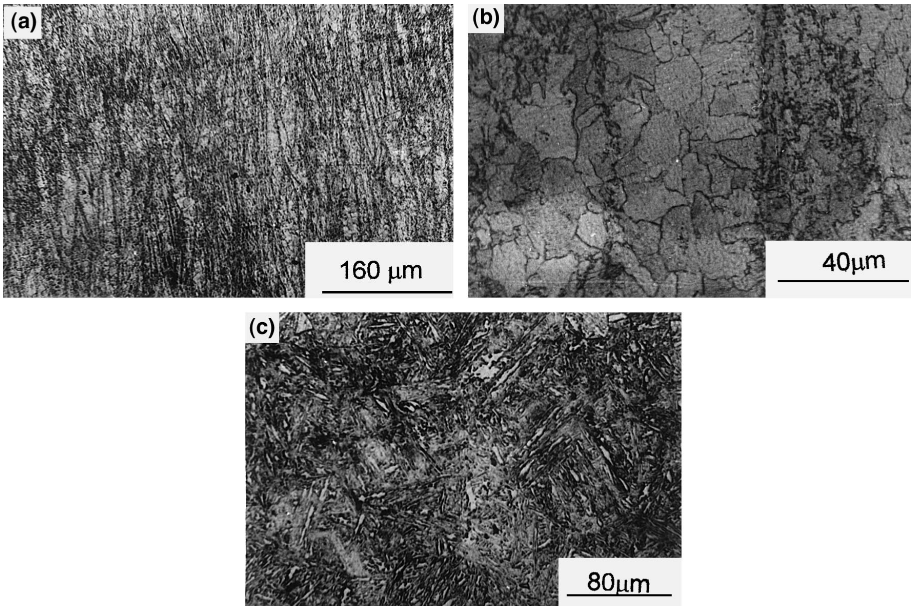

Fig. 1. Microstructure of the 9Cr–1Mo steel billet in transverse direction. (a) AR condition at lower magnification; (b) AR microstructure at higher magnification; (c) in 710T condition.

is typical tempered martensite, with no evidence of banding (Fig. 1(c)).

The AR plates were rolled in a two high mill (roll diameter = 190 mm) at room temperature such that the rolling direction parallel to the transverse direction. Cold rolling was done under heavy lubrication (using lubricating oil) in order to minimise the friction, which is suspected to be possible cause of alligatoring [5]. The rolls were greased after each pass. The plates started failing by alligtoring after a reduction in thickness of about 30%–40% during room temperature rolling (with a reduction ~5pct/pass) (Fig. 2). Rolling of rods (~25 mm in diameter) cut along the transverse direction of the billet were also attempted and the material also failed by alligatoring. The 710T plates were rolled under exactly similar conditions at room temperature and the plates could be rolled from a thickness of 20 to 2 mm without alligatoring defect.

3. Results and discussion

The phenomenon of alligatoring in this steel can be attributed to the presence of carbides lying as bands parallel to the sheet rolling direction. The carbides in the centre plane of the plate are under tensile loading during the initial stages of rolling [2] and the voids nucleate at the carbide–matrix interface. The voids subsequently join up to form small cracks. As more voids accumulate, the crack extends in length, in the direction of rolling, with increasing strain (Fig. 3). The stresses in the plate are expected to reverse as the plates become thin [1]. This should cause tensile stresses away from the centre plane and the cracks should form in these planes as well at the carbide–matrix interface. Fig. 4 shows stable cracks in the planes away from the centre plane. The cracks are not expected to 'heal' in the course of rolling because of the carbide particles within them. The final failure is further assisted by the concavity developed at the front end of the sheet which can act as stress riser [2]. This acts as the initiation site for the alligatoring failure. The normal stresses that exist at the front end of the plate at the exit from the rolls, is sufficient to spilt the slab along the centre plane, which is already weakened by small cracks. Thus the failure is invariably along the centre plane of the sheet even if cracks are present in other planes as well.

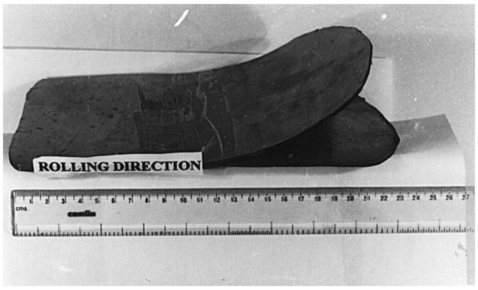

Fig. 2. Failure of AR material by alligatoring after about 40% reduction at room temperature rolling.

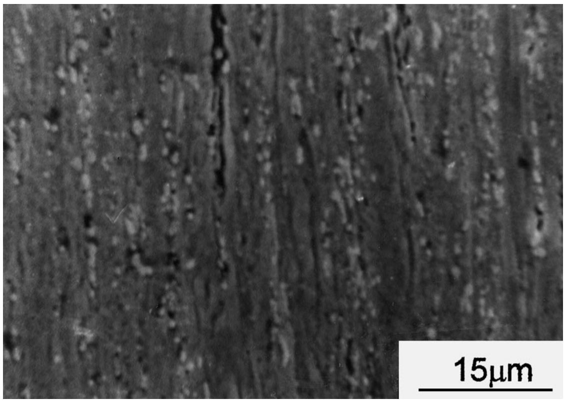

Fig. 3. Micrograph showing cracks associated with carbides.

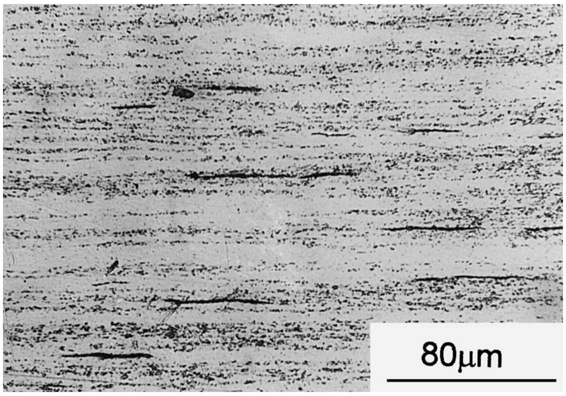

Fig. 4. Multiple cracks at planes away from centre in the sheet failed by alligatoring. These cracks remain stable and do not take part in final failure.

In order to examine the role of the concavity on the alligatoring defect, the concaved front end was trimmed after a 20% reduction and the rolling continued. These plates again failed by centre splitting after about 25%–30% further reduction. The removal of concavity, thus, seems only to prolong the onset of damage. But repeated trimming of the front end of the slab, in the course of rolling is reported to have beneficial effect in alligatoring problem [2]. In the present case, the trimming can expose the cracks in the centre to the front end of the plate and this can act as stress riser. Such a situation may not be present if the microstructure is not banded [2].

It should be noted that the same material under identical rolling condition did not fail by alligatoring when the banded microstructure was eliminated by the 710T treatment. The precipitates formed by this heat treatment are much finer (0.1 μm) [6] than those in the AR condition (∼3 μm, Fig. 3) and are distributed uniformly. These fine precipitates will not decohese easily and nucleating a void at the carbide–matrix interface is made difficult. Even when the voids form at the carbide–matrix interface, their chance of getting interconnected in to a crack is less because of uniform distribution of carbides. However, the alligatoring was reported in the 1090 plain carbon steel even when the spherodised carbides were distributed uniformly. One probable reason for this difference in behaviour between the present and the reported work [2] appears to be the fairly large size of the carbides in the latter, which is susceptible to decohesion. It is difficult to comment at this stage on the influence of the carbide types on the strain to nucleate interfacial voids.

4. Summary

1. Alligatoring damage was found to occur in a modified 9Cr–1Mo steel if the microstructure was banded, due to segregated carbides and could be alleviated if the banded structure was destroyed through a conventional normalising and tempering treatment.
2. When the microstructure is banded by the segregated coarse carbides, the alligatoring damage is facilitated by the cracks formed by the inter connection of the voids at the carbides. The concavity at the front end can help in the final failure of the sheet. Trimming of the front end could not prevent the alligatoring failure.

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