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Failure analysis of recurrent cases of fatigue fracture in flash butt welded rails

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ABSTRACT

Medium carbon steel rails are commonly jointed by flash butt welding procedures. To ensure an adequate service life for the structural component, commonly subjected to fatigue loading, a rigorous quality control should be performed, both in welding parameters and in the surface quality of the welded joint. This work investigated the causes of recurrent failures in railroads, with cracking always initiated in the rail in the region of the welded joint. Two case studies are presented. Aiming to execute the failure analysis, all standard procedures were applied, with a careful assessment of the material characteristics and the fractured surface. It was concluded that, for both cases, fatigue cracks initiated near the weld bead and spread in a brittle mode, leading to premature fracture of the material. An in-depth analysis of the rails showed that the surface finishing of the weld bead was not appropriate, generating undesirable stress concentration. Some undesirable microstructural characteristics were also found in the weld region. A recommendation to control welding parameters and to change the procedure of surface finishing of welded joints was held, aiming to decrease the number of accidents on the railroads.

1. Introduction

In continental countries like Brazil, logistics questions related mainly to the transport of high volumes for long distances must be accurately treated. The railroad is one of the most efficient and economical transport ways to attend this demand [1]. The Brazilian railroad network is used by many companies (for example, VALE, one of the largest iron ore companies in the world) for transportation of minerals, agricultural products and passengers. The railroad sector adopts the American AREMA Manual for Railway Engineering [2] for design, manufacture, joining and maintenance of steel rails.

The railway transport is an efficient transport way mainly if railroads have their integrity preserved during their service lives. Rails catastrophic failures during a train passage, may cause the train derailment, resulting in accidents with human lives and material goods losses [3–8]. Aiming to increase the railroad service lifetimes, nowadays the manufacture of rails use modern steels with high mechanical strength and wear resistance. The majority of rail steels has an eutectoid composition with a pearlitic microstructure. The prior austenitic grain size, the pearlite colony size and the interlamellar spacing are factors that need to be controlled [9]. In addition, the proper choice of phases and constituents for steel, as the bainitic structure, can provide high values for tensile and fatigue strengths, and a good performance in service [10]. Moreover, due to the need to increase train capacity, size and speed, specific settings for the construction of railways have been employed. One example is the use of long welded rails in railway construction also continuously welded [8].

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Structural deterioration phenomena, which typically cause failure of modern rails, commonly involve stress and strain control fatigue and are related with wagon wheels and axles, and mechanical interactions with rails. Moreover, welded joints are microstructural discontinuities in railroads continuously welded and represent susceptive points for fatigue cracks nucleation and growth [7,8,11–13].

Nowadays, two welding processes are often used: flash butt welding and thermite welding. Flash butt welding is used to weld short rail sections aiming to obtain longer sections (400 m). This welding procedure is often done in a welding plant. The longer rail sections are then transported and welded one to the other in the track by thermite welding procedures.

The flash butt welding is a resistance welding method, often performed in stationary plants, which consists of electrical heating and hydraulic forging of the rail ends. On the other hand, the thermite welding method is a casting method and it is the most common method used in the track to make sections together. However, according to technical literature, both types of welding methods introduce a similar residual stress field in the foot, the web and the head of the rail. Many authors, using experimental and computational data, describe the welded rail web as the highest tensile residual stress area after fast cooling. According to them the residual stress distribution is very important to understand the rail fracture mechanism [14–18]. Another problem is that these rails are mainly constituted of pearlite and during the welding procedure the microstructural changes that happens in the heat-affected zone (HAZ) may degrades the mechanical welded joint properties. According to preview studies, the cementite is commonly globulized in this area and the yield and tensile strength locally decrease. In the welded zone, it is possible to occur austenite grain growth and carbide precipitation in their boundaries. These precipitations may decrease especially the steel fracture toughness [13–18].

In this context, this research investigated, from several recurrent cases with similar characteristics, the cause of two failures in flash butt welded joints of high strength rails used at Brazilian railroads, which were failed and caused serious accidents. These failures were considered arising from mechanical fatigue in rails, due to the nature of the stresses on the rails and observed characteristics in the analysis. The loads acting on the rails (about 200 kN) induce a stress state below the tensile yield stress of steels used in rails, and no overload was considered in these analyses. The failures in welded joints were analyzed and the main results were related, aiming to understand the causes and suggest improvements to the rail welding procedure.

2. Materials and methods

Standard procedures for failure analysis were applied in this work aiming to investigate two failure cases in flash butt welded joints. The fractured joints were preserved, sampled and submitted to several characterization methods.

The executed failure analysis involved the following principal stages: investigation about material's fabrication and use history, sampling procedures including the preservation (cleaning) of the fractured surface, macro and microfractographic analysis, chemical analysis, metallographic analysis and mechanical tests (tensile and hardness tests) for both samples.

3. Results and discussion

3.1. Case 1

3.1.1. Macrofractographic analysis

Fig. 1 presents the inferior part of the fracture surface of the rail, which was used in the macrofractographic analysis. It is possible to observe the fracture aspects at the head and at the web of rail. The rail web presents a region that reflects more intensely the light (flat and brightening). Fig. 1 also shows that this flat region is localized at the internal side of the railroad, where train wheels exert higher fatigue efforts over the structure. It is important to observe in this Figure the bad quality of the superficial

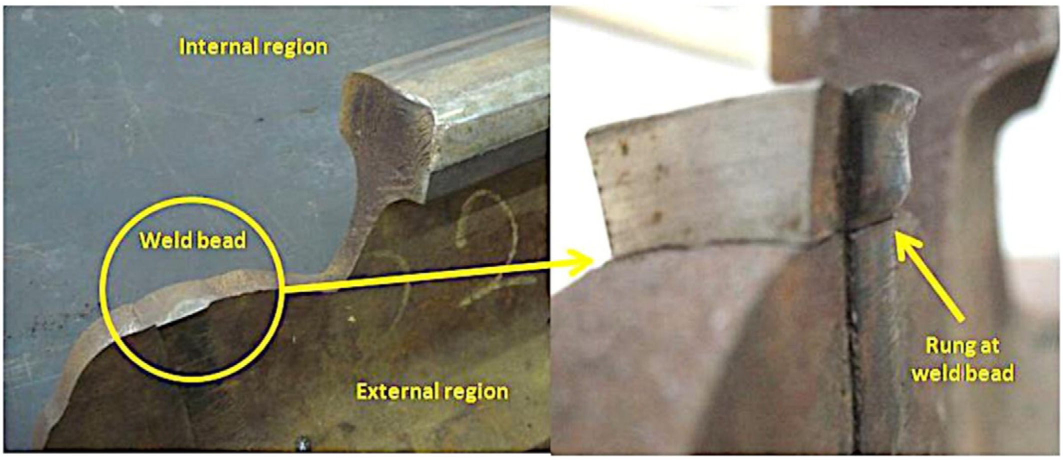

Fig. 1. Rail fracture surface, highlighting a rung at the welded bead.