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Process Design Optimization for Welding of the Head Hardened R350 Ht Rails and Their Fatigue: A Literature Review

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Abstract:- This survey presents a literature review on the welding of head hardened rails with a special focus on final structure of rail due to the contact conditions between the cooling process and the pearlitic structure. The experimental studies have been conduct under rails to observed austenitic transformation time and temperature, squeeze and hold time. In this investigation have been focus to the characteristic of fatigue and the hardness of railhead. According to that the idea of research are design and optimization-cooling system after welding head hardened rail to control the cooling process using both the experimental and simulation. Optimal operation tests parameters was obtain via European standard, which were EN14587-1 and EN14730-1.

Keywords: - Head Hardened Rail, Welding, Pearlite, Cooling Process, Fatigue, Rail Tests.

I. INTRODUCTION

Legacy systems with a man or horsepower, and the beginning of tracks or rail made of wood, the transport by rail history dates back as far as civilization started. With the beginning of the eighteenth century was the railway one of the most dramatic growth developments, especially in the nineteenth century [1]. However, the story of the railway in that period was one of the masterpieces of engineering and the way in which these technological changes have helped to transform society. Later on, by development with increase trains performance and increasing demand to transportation in all world especially nowadays in urban and interurban, to satisfy the need for means of railways comfort, safe and fast, the development of high speed railway systems which rapidly decreased the journeys time needed [2].

Reviewing and improving the old studies with new improvements have become important and crucial. The importance of the railway is increasing, especially in countries where large spaces, the world is being evaluated engineering and research for welding joints in the rail control procedure in terms of hardness, corrosion resistance and the development of cracks and deviation. To avoid human disasters or economic.

Although the fracture because of the spread of fatigue crack is still great demand as confirmed by the current special issue. The importance of rails comes as the heart of the railway system. Which are subjected to the extremely high service loads and hard environmental conditions [3]. However, in modern railway utilization rails are exposed to a continuous rise of speed and loading on the vehicle axles and to continuous stress increase as well in welded joint of railway tracks [4]. According to that the idea of research are design and optimization-cooling system after welding head hardened rail to control the cooling process using both the experimental and simulation.

II. RAILS WELDING

According to American Society of Welding, welding is a localized coalescence of metal where coalescence is produced by heating to suitable temperature, with or without the use of filler metal [5].

A. Flash butt welding

Flash butt welding technique spread to many countries during the 1930s but much of this development work came to a standstill during the war years particularly in the U.K. and on the Continent. However, by 1950 the flash butt welding of rails was common place in all major railroads throughout the world [6]. The flash-butt welding process is a method of joining metals together by heat and with noting that rail section is consumed per weld, the heat necessary to weld the joint is generated by the resistance of the rails (an electrical current). Unlike the Thermite welding and Arc welding processes, no additional chemicals or metals are required to make the weld and in fact, the reverse is the case, and unlike arc welding which is the welding point moves along a welding line. Mechanism of Flash butt welding process, that the two rail ends to be welded are firmly held by the clamps of the machine. One side of rail end is fixed while the other end can move. It is brought to the ends of the rail near each other until they nearly touch.

After that, the electricity is switched on and made to pass through the interface of the two rails. In the process heat is generated and flashing takes place. The moving end is then moved away but brought back after some time, as showing in figure(1). The entire welding process consists of a preheating process, flashing process, upsetting process, and trim¬ming process. This process continues specific number of courses in accordance with a predetermined rate of sequence. When the temperature increase to an end fusion, and the pressure is on both sides of the railway along with the use of force, which leads to welding to the ends of the rail, resistance welding processes it is important Joule’s law formula (1).

$$Q=I^2 . R .t, \ J \tag{1}$$

Where:

I: Welding current (A),

R: Resistance (Ω),

t: Time(s)

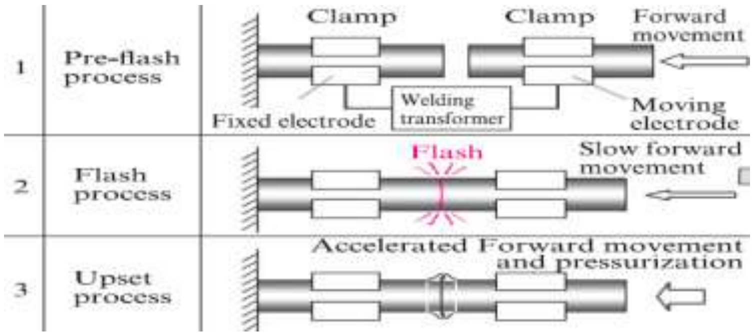

Fig.1: show flash-butt welding mechanism and Joule’s law .

B. Thermite welding

In 1893 Hans Goldschmidt of Germany began to experiment with aluminothermic reactions (highly exothermic processes involving reactions of metallic oxides with aluminum powders) for the production of high purity chromium and manganese [7]. This work, led to a patent application for the Thermite process in 1895, and sales of chromium rapidly increased especially at the end of the 19th Century. The thermite process has been successfully used to make repairs to large cast and forged steel parts, compression welding using the heat of reaction products had been performed and the first rails were joined.

Alumina thermic process is based on the chemical reaction of iron oxide with aluminum. The reaction, existence ‘exothermic’ is associated with heat generation. Depending upon the particular oxide of iron used as shown below, the reaction can liberate heat energy sufficiently high to even vaporize the resultant iron [6].

$3Fe_3O_4 + 8Al = 4Al_2O_3 + 9Fe$ [30880C, 719.3 Kcal] (2)

$3FeO + 2Al = Al_2O_3 + 3Fe$ [25000C, 187.5 Kcal (3)

$Fe_2O_3 + 2Al = Al_2O_3 + 2Fe$ [29600C, 181.5 Kcal] (4)

Mechanism of Thermite welding is to apply it for joining two ends of rail together by casting molten steel inside a template that has been placed around the spacing between the two rail ends. The rail ends of the rail must be straight and the correct welding gap established. The rails must be sit properly aligned with the faces free of corrosion, grease and dirt.

The thermite welding reaction, is promoted by a mixture of powders called the thermite mixture, as showing at figure (2). The thermite mixture consists of oxidized iron and metallic aluminum as the reaction constituents along with alloy additives like ferromanganese or the like and the composition of this mixture is adjusted so that the composition of the weld metal comes close to that of the rail. The thermite mixture is poured into a melting bot set above the mold, and the reaction is started by an inflammation agent in the form of a pyrotechnic agent.

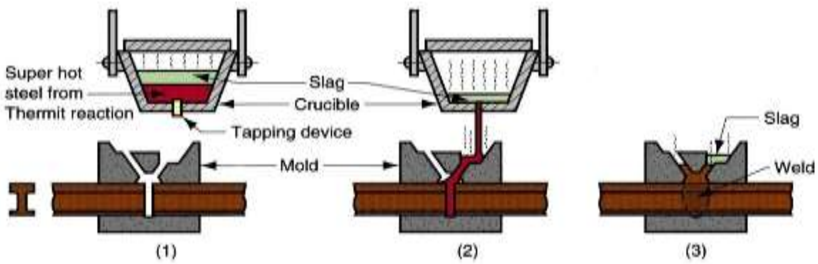

Fig.2: showing Thermite welding process: (1) Thermite ignited, (2) crucible tapped, superheated metal **flows** into mold, (3) metal solidifies to produce weld joint

III. RAIL-WHEEL INTERFACE

Since beginning adhesion is a force acting at the wheel rail interface, wheel rail contact conditions need to be discussed head most. this situation different with other means of transportation like road vehicles and aircraft, railway vehicles run on rails that are fixed to the ground through sleepers and ballasts. The guiding performance of the railway vehicle system is specified by interaction between the wheel and the rail profiles, which mention to the shapes of the wheel and rail [8].

The railway system is complex. The dynamic response of a load vehicle hardly depends on the interaction between vehicles and rails respectively vehicle and the transported goods [9]. Main requirements for the technology used in load transport systems are cost and safety efficiency. Because of the complexity with different conditions in different countries an introduction of new types of running gear or enhancement in operational conditions such as rise axle load and speed, must be made at high caution.

In order to understanding rail wheel inter face we should know the complex longitudinal stress state in a rail as showing in Figure (3).

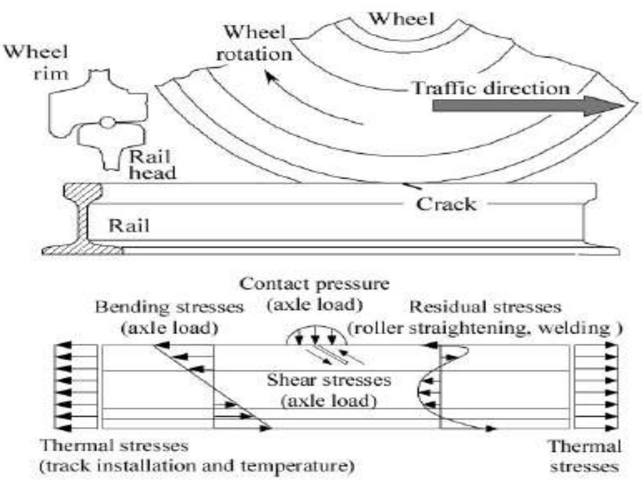

Fig.3: a) A wheel rolling on a continuously welded rail, b) Contact stresses and longitudinal stress components [3].

IV. FATIGUE MECHANISM

Fatigue is that a problem which human has faced for as long as there have structures made by men. Moreover, the problem might actually be worse in these days than in previous centuries, because more can go in error in our complex technological community. Major trains crashes, for instance.

Fortunately, advances in the field of fracture mechanics have helped to substitute some of the chance dangers posed by increasing technological complexity. Our understanding of how materials fail and our ability to prevent like failures have risen considerably since World War II. Much remains to be learned, however, and existing knowledge of fracture mechanics is not always applied when appropriate [10].

The railway fatigue as an outcome of the development of fatigue cracking is considered as a dangerous event in the railway industry as it is probable to result in vehicle derailment with a high probability of loss of life. Cracks in railways have been appearing on the head of the railway as a outcome of mechanical damage consequent to wheel-rail contact stresses, or the foot of the rail emanating from corrosion pits. Newly, since the method of joining railways by fishplates was abandoned in favour of continuous welded rail, different source of cracking was introduced arising from dissimilar weld defects.

Fatigue cracks in railways can be started at the railhead, the web and at the foot. Their growth can lead spelling of material fragments which will affect by noise and the travelling comfort and as well dynamic load magnification for track and rolling stock together. Unfortunately, If not detected at the exact time the fatigue cracks can furthermore lead to fracture of the railway which in sometimes may cause derailment.

Subsequently, the possible failure scenarios included the nucleation and growth of possibility fatigue cracks must be known as a necessary basis for estimated of damage tolerance. a brief overview of the farthest important crack types and failure scenarios. Modern railway production technology and utilization in European Community have required a new philosophy and content of proposals for the new European standards for manufacture and delivery railway rails such as series EN13674 and other recommendations [4].

Cyclic fatigue includes the failure of materials under cyclically degrees loads and microstructural damage. However, Structural materials are most of time designed with compositions and microstructures optimized for fatigue resistance [11]. In general, Fatigue cracks started at the railhead, web and foot. High

Propagation of initiated cracks can reason painful failure of the rail. The steel on steel contact of railway rails and wheels happen in an open system. The pursuit of travelling fast and carrying more has led to ever raise contact force between the wheels and rails. Moreover, because a specific level of friction is needed for traction and braking, rail wheel contact is commonly not lubricated wear and tear is therefore inevitable [12].

V. MECHANICAL PROPERTIES INVESTIGATIONS

Familiarity about the mechanical properties of the rails surface is important for optimizing the selection of rails materials. Moreover, It is proven that rolling sliding contact between the surfaces of ductile materials is mostly accompanied by tough plastic deformation localized to a little volume of material close to the surface [13] [14]. The quality of rail materials is very important for reducing wear and other forms of rail degradation.

The most common railway steel are pearlitic steel, which its behavior under large plastic deformations is controlled by the changes in its lamellar microstructure. Where, pearlite is a two-phase material consisting of colonies with preferred directions of cementite lamellas embedded in a softer ferrite matrix [15] [16]. As showing in figure (4).

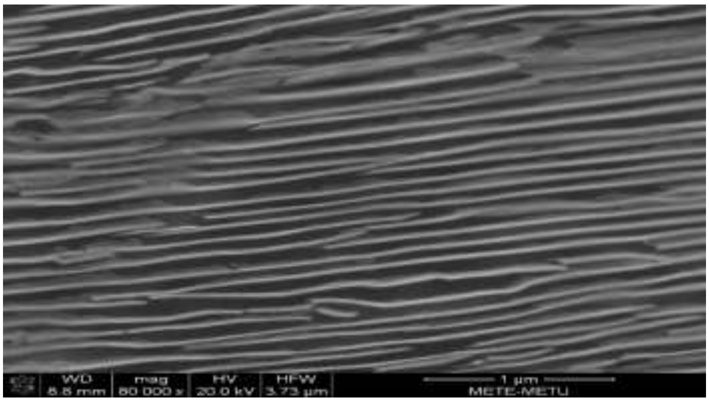

Fig.4: showing pearlitic interlamellar microstructure.

VI. LITERATURE SURVEY ON COOLING AFTER WELDING HEAD HARDENED RAIL

Literature exhibits that work has been search on several aspects of modeling, simulation and process optimization head hardened rail . In this study, detailed analysis has been made to establish design and optimization-cooling system after welding head hardened rail to control the cooling process using both the experimental and simulation.

(Alfred Moser and P. Pointner, 1990) [17]. Head-hardened rails are used in tracks subjected to maximum stress, these rails are generally manufactured by induction heating of the rail head with subsequent accelerated cooling. By cooled down immediately from the rolling heat in such a way that the fine pearlitic structure essential for optimum wear properties is achieved in practically the whole area of the head.

(Satyam S. Sahay, Goutam Mohapatra, and George E. Totten, 2009) [18]. Control of chemistry and thermo mechanical processing is required to obtain the desired pearlitic micro structure with fine lamellae spacing. This is carried out by the pearlitic transformation at the lowest possible temperature. It is important to precisely control the phase transformation during thermo mechanical processing to obtain the desired microstructure and mechanical properties of the rail steel.

(Koczurkiewicz Bartosz, Dyja Henryk, Niewielski Grzegorz, 2015) [19]. Was tried to describe the dependence of the distance interlamellar space as a function of the cooling rate after deformation. For determine the influence of cooling conditions of high carbon wire rods on the morphology of pearlite thermo-plastic modelling, by using deformation dilatometer DIL 805A / D and After deformation samples were cooled down with different cooling rates, this cooling conditions guarantee the formation of pearlitic structures with the average distance interlamellar equal to, or less than 0,2 µm.

(Aldinton Allie, Heshmat A. Aglan and Mahmood Fateh, 2010) [20]. The pearlitic steel displayed ductile fracture features immediately ahead of the crack tip but approaching the end of the fracture surface the failure mechanism became less ductile. The welded rail steel in contrast consists of ductile features throughout the entire fracture surface. The hardness of the weld and HAZ may be increased by heat-treating the rail using a specific type of hardening technique, either induction or flame hardening.

(Asitha C. Athukorala, Dennis V. DePellegrin, Kyriakos I. Kourousis, 2016) [21]. The hardness of rail head studied and has been found that hardness reduces highly below four millimeter’s from the rail top surface. Moreover, the microstructural features were also analyzed, especially the pearlite interlamellar spacing, which showed strong linkage with both hardness and cyclic plasticity behavior of the material.

(Gladman, T. Pickering, FB. 1982) [22]. According to their study, the pearlite micro structure and mechanical properties during processing can be tailored through variation of the interlamellar spacing, which is directly related to strength.

(A.M. Elwazri, P. Wanjara, S. Yue, 2005) [23]. Was found that, the mean value of the interlamellar spacing was observed to increase with increasing reheat and transformation temperatures. Examination of the mechanical properties of the resulting pearlitic micro structures indicated that the strength was related primarily to the interlamellar spacing by a Hall–Petch type relationship, while the ductility was dependent also on the prior-austenite grain size and pearlite colony size.

(O.P. Modi, N. Deshmukh, D.P. Mondal, A.K. Jha, A.H. Yegneswaran, H.K. Khaira, 2001) [24]. The mechanical properties of a steel containing a nearly fully pearlitic structure have been examined as a function of the interlamellar spacing. Also Hardness and yield strength follow a Hall–Petch type of relationship with inter lamellar spacing.

(J. Toribio and E. Ovejero, 1998) [25]. Interlamellar spacing in fully pearlitic steels decreases progressively during the cold drawing process and this diminishing rate is not constant throughout the manufacturing route, since the disposition of the plates and their progressive orientation in relation to the stresses they are undergoing govern the behavior of the colonies during the process.

(N. Yu. Zolotorevsky, Yu. F. Titovets and D.M.Vasiliev, 2004) [26]. Found that Heavily drawn pearlite represents, as a nano composite with thickness of ferrite and cementite lamellae decreasing with drawing. The strength of the drawn pearlite increases up to very high level with this lamellar structure evolution.

VII. RAIL TEST

In general, visual examination is the first test after the welding of the rails where visible defects of geometry are the target, which carried out by the welding technician on sight. on other hand, The micro- and macro structure examination, hardness test, bend test and fatigue test all tests done in the laboratory [27].

the both TW and FBW welds tests methods are the same, which flash-butt welding requirement given in European standards EN 14587-1 and the requirements for thermite welding process are given in European standards EN 14730-1 Railway applications.

A. The hardness test

The resist plastic deformation are the main property of the hardness of a material which usually measured by penetration. Rockwell vs Vickers hardness testing are measurement techniques according to EN 13674-1. Moreover, the hardness values measured shall meet the requirements given in Table (1) for the relevant grade, where 1,2,3 and 4 Location of hardness testing showing in figure (5). [28].

Table I: Hardness testing positions and requirements.

Position	**Rail Steel Grade**						
	200	220	260	260Mh	320Cr	350HT	350LHT
	Hardness (HBW)						
RSa **1** **2** **3** **4**	200-240	220-260	260-300	260-300	320-360	350-390b 340 min 331 min 321 min 340 min	350-390b 340 min 331 min 32 min 340 min
a RS= Point on the center line surface. b If the hardness exceeds 390HBW, the rail is acceptable provided the microdtracture is confirmed to be pearlitic, and the hardness does not exceed 405 HBW.							

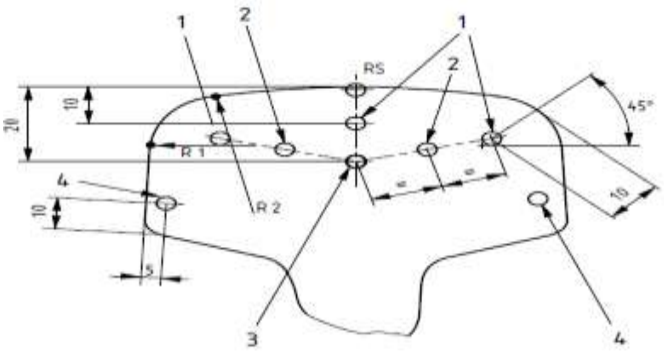

Fig.5: Showing 1,2,3 and 4 Location of hardness testing (see Table 1).

B. The bend test

The bend test is a simple and inexpensive qualitative test used to evaluate both the ductility, safety and quality of rail weld as well. The bending test as same as hardness test, the same requirements in both European standard EN 14730-1 and EN 14587-1, 3-point bend test as showing in figure (6).

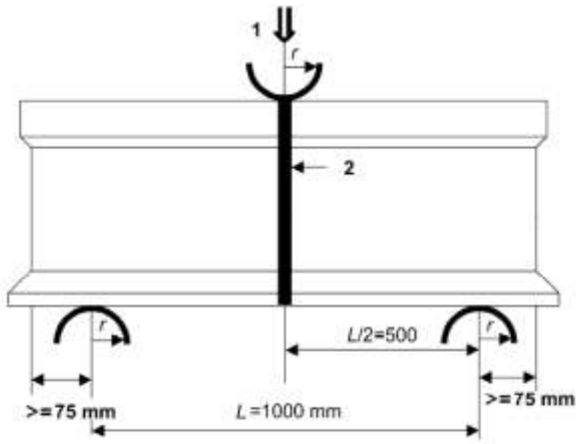

Fig.6: Showing the bending test. 1 Load, 2 Weld, 25 mm ≤ r ≤ 70 mm, Minimum sample length = 1150 mm and Loading rate ≤ 60 kN/s. [28].

The load shall be applied to the running surface of the weld by a single fulcrum, also the fracture shall be the end of test.

C. The Fatigue test

Accordingly, to EN 14730-1 Thermite welding and EN 14587-1 in of flash butt welding, which in both processes a rail weld shall be with a 4-point bending with the rail foot in tension as cleared in figure (7).

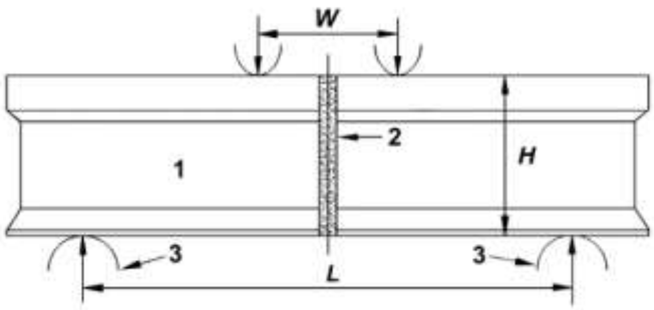

Fig.7: Show bending test, where 1 Rail, 2 Weld and 3 Bearer. [28].

VIII. CONCLUSIONS

A literature review support and helps to visualize the main behaviour of the head hardened rails to analyze the influence of different microstructure and their effected on structure as well as mechanical properties including boundary conditions of cooling process. Moreover, it is found there are remarkable works carried out in the field of rails cooling process. Nevertheless, most of that works carryout only for standard steel specimen not for R350HT. The increasing knowledge produced about the process and computer resources can lead, maybe in a near future, to the use of numerical simulation of welding and cooling process to predict a good combination of the process parameters and condition also replacing the experimental trials, which actually used nowadays.

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