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APPLICATION OF AUSTEMPERED DUCTILE IRON TO RAIL WHEEL SETS

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ABSTRACT

Austempered Ductile Iron (ADI) is made up of a composite structure of acicular ferrite and carbon-enriched austenite. The transformation of austenite to martensite under certain stress levels results in a material with a hard rim and a tough internal structure. These properties makes it an alternate material for the production of railcar wheelsets.

Key Words : Austempered ductile iron, Railcar wheelset

OSTEMPERLENMİŞ KÜRESEL GRAFİTLİ DÖKME DEMİRİN VAGON TEKERLERİNE UYGULANMASI

ÖZET

Ostemperlenmiş küresel grafitli dökme demirin asiküler ferrit ve karbonca zenginleşmiş ostenitin bir kompoziti olarak tanımlanan bir mikroyapısı vardır. Karbonca zengin ostenitin gerilim altında martensite dönüşebilmesi sonucunda dışı sert, içi tok bir malzeme elde edilir. Bu özellikler vagon tekeri üretimi için alternatif bir malzemeyi ortaya çıkarmaktadır.

Anahtar Kelimeler : Ostemperlenmiş küresel grafitli dökme demir, Vagon tekeri

1. INTRODUCTION

Wheel sets for railcars are supplied from external sources. Formalities in import procedures and problems in financing and due dates lead to inevitable delays. The unavailability of such wheelsets from internal sources arises as a problem of both technological deficiency and lack of economical capacity. Long due dates in wheel set supplies arises not only from internal demand but also from international demand. (Dündar, 1990) Developments in rail wheels are reviewed to guide the domestic production towards the increased demand.

1. 1. Freight Car Wheel Design

Of all the components that comprise a freight car, wheels have the toughest job. Supporting the weight of a heavily loaded car, they withstand extreme thermal and mechanical stresses caused by such factors as brake shoe friction, pounding from rail joints and special trackwork. The manufacture of freight car wheels today is a blend of forging and casting. The three major wheel manufacturers are Griffin Wheel, Standard Steel, and ABC-NACO.

Wheel design changes are restricted to plate shape and radii, and to where the plate intersects with the hub and the rim. All wheel designers are limited in what they can do, because tread geometry is governed by the Association of Railroads.Tread and hub designs are pretty much fixed due to axle, bearing, and rail interface requirements.

Working within these constraints, wheel designers are able to devise substantial refinements that improve stress response and contribute to longer, defect-free wheel life. Standard Steel's new wheel designs are developed with the aid of computer-based finite element . The increase in service loads has created more stress on wheels and made designs more sensitive. Increased car lading, larger braking loads with longer trains and higher horsepower locomotives are critical design factors. Use of dynamic brakes and the changeover from cast iron to composition brakes shoes has substantially reduced wheel failures. Heat-stress-related failures (cracking, breaking) have gone from being the prominent cause of wheel failures to almost zero. What the industry is now seeing are mechanical-load-related failures (spalling, shelling) caused by high-impact loads from slid flats and built-up (out-of- round) treads and higher axle loadings. However anything done to strengthen a wheel increases its susceptibility to spalling from wheelslide. Spalling occurs when martensite (created by rapid heating and cooling during wheelslide) forms on the wheel tread.

Griffin, which pioneered the low-stress wheel with a parabolic deep-dish design in 1964, begins with molten steel. The steel, transferred to a ladle, undergoes "controlled pressure pouring" to make the wheel casting. The ladle of molten steel is sealed in a chamber with an airtight cover, to which a ceramic tube is attached. Air forced into the chamber pushes the steel up through the tube and into a graphite mold machined to the appropriate wheel contour. The mold is positioned over a pouring tube; the steel fills the mold from the bottom to form the wheel. Because the steel is forced into the mold at a controlled rate, the wheel is cast to very close tolerances, eliminating the need for machining. This process also limits re-oxidation of the steel, which results in very clean steel. The wheel casting solidifies in 7 to 12 minutes. The cope (top) of the mold is removed, and the wheel is lifted by its hub and conveyed to a cooling kiln to reduce stress formation. Riser stubs (casting sprues) are removed using hot-wheel grinding machines. Next, an oxypropane hub-cutting torch cuts out the wheel hub. The wheel then goes to a gas-fired rotary-hearth normalizing furnace for heat treating, which improves its metallurgical structure and relieves internal stresses. This is followed by rim spraying with water to harden the wheel tread. After quenching, the wheel is tempered and shot-blasted to improve its surface appearance. The wheel then undergoes several tests. With magnetic "blacklight" particle test , the particles line up at discontinuities in the material, allowing the blacklight to show surface defects. An ultrasonic test checks for subsurface flaws. Brinell test determines hardness. A wheel peener induces compressive stresses on the plate surface. Finally, the hub is rough-bored.

ABC-NACO's casting process uses a graphite mold where the perimeter (tread) section is graphite, and the internal (plate) section is sand. This takes advantage of directional solidification, where the wheel solidifies from the outside in (Figure 1). The graphite at the tread profile acts as a chill which drives the solidification from the tread back toward the hub, which creates 'uni-axial' distribution. ABC-NACO looks at "macro-cleanliness," which deals with large inclusions and voids, and "micro-cleanliness," for microscopic inclusions and voids.

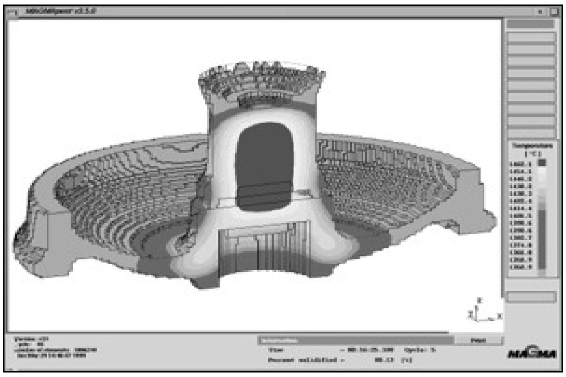

Figure 1. Solidification pattern in graphite mould (Vantuono, 2000)

Standard Steel produced the first solid forged, rolled and heat-treated wheel in the U.S. Standard Steel uses an exclusive cylindrical bottom-pour ingot process. Ingot blocks, after being cut into precise wheel blanks are heated in a computerized rotary hearth furnace to 2.300 degrees F. The blanks are forged into a pre-form shape on a 10.000-ton press, then rolled to their net shape on a computerized vertical wheel-rolling mill equipped with a laser measurement system (Figure 2). Rolling is followed by dishing into an "S" plate shape and center-hole punching.

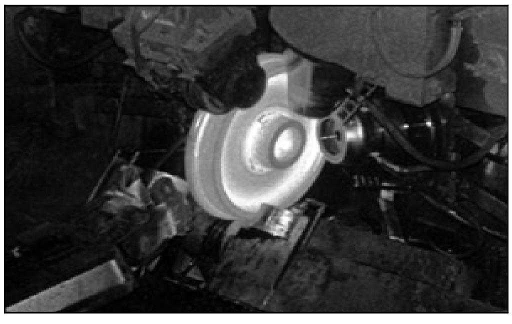

Figure 2. Wheel rolling equipment (Vantuono, 2000)

The Nolan company recommends the use of its special ductile alloy cast wheels instead of pressed steel wheels. Nolan's cast wheels are tougher, have a larger load capacity and last many times longer. (Nolan, 2002)

1. 2. ADI as An Alternative Wheel Material

The idea of producing ductile iron castings with bainitic matrix structures and good combination of properties including high strength, ductility, toughness and wear resistance using austempering heat treament has gained considerable attention in recent years. (Özel, 1988) ADI (Austempered Ductile Iron) offers qualities, which promise to meet the demands of the railroad industry for quieter, lighter, components, while reducing life-cycle costs. In fact rail to wheel contacts with high normal loads and a contact area of approximately $1cm^2$ represent one of the highest loaded roll and slide contact conditions encountered in steel. The "self-lubricating" capability of ADI seems to make it an interesting alternative to commonly used steels with respect to maintenance. When compared to steel, ADI exhibits three times higher damping and promises a decrease in traveling noise. A further advantage is that ADI has a 10 % lower density (compared to steel), which allows for lower weight components. The reason for this lower density is the presence of graphite nodules in the matrix structure. These graphite nodules also positively influence the wear characteristics, by acting as a lubricant between the contacting parts (Madler, 2000).

Production of Austempered Ductile Iron (ADI) is a two way stage process. (Özel, 1988) The casting is first austenitized by heating to a selected temperature in the range of 815-900 ºC to obtain full transformation of the matrix structure to austenite an then transferred quickly into a salt or lead bath preheated to a temperature range of 250-450 ºC for a time sufficient to obtain mainly bainitic matrix containing some residual austenite, provided that high quality spheroidal graphitic cast iron is used. The base metal must possess good nodularity (minimum 80 %) and its nodule count must be better than 150 nodules/mm^2 in a 25 mm diameter section. The composition of the base iron is also a critical factor and the presence of some alloying elements are necessary to obtain the required degree of hardenability. However some alloying elements have tendency to segregate to cell boundaries during solidification. Segregation causes non-uniform carbon solubility and distribution, impovering the austempering reaction rate, affecting the structural morphology and the mechanical properties and machinability. The effects of alloying elements of Mo and Ni and basic heat treatment parameters of austenitizing temperature and time on the austempering behaviour of spheroidal graphitic iron was investigated with particular reference to the effects on unnotched impact resistance and Brinell hardness.

The Finnish National Rail System (VR) already has experience with the application of ADI for railway wheels (Jokipi, 1991). In company experiments, they have used ADI (with a minimum tensile strength of 980N/mm2 and 5 % elongation) since 1976 for switching locks and, since 1981, for passenger train car wheels. These wheel experiments demonstrated an estimated 30 % reduction in life-cycle cost (from purchase to scrapping).

Replacing steel components with ADI has also been investigated by Railway Research Institute of Japoan Railways concentrating wear tests on Kymenite (Johansson, 1997).

The Research and Technology center of the Deutsche Bahn AG (DB AG) has been conducting testing regarding the feasibility of ADI for rail systems. (Madler, 2000) The suitability of ADI as a vibration damping material with higher wear resistance for disk brake equipped wheels with speeds of up to 160 kmph has been examined. Manufacturing methods, component testing, and the estimation of the real to expected damping of traveling noise by using acoustic simulations have been investigated.

One criterion in the selection of wheel materials is their rolling and sliding behavior. To estimate these behaviors ADI was examined in rolling contact with a DB AG rail steel on a roll wear-testing stand. The ADI wear samples were made from a readily available ductile iron track plate. A Cu, Ni and Mo alloyed ductile iron, whose Mn content was limited to 0.3% was chosen for the first test wheels. The track plates were austenitized in an inert gas atmosphere at 910 °C, quenched briefly in a salt bath operating at 220 °C, then immediately transferred to a second salt bath for isothermal transformation (austempering) at 370 °C. The test samples were then machined from the austempered plate(s). To test the homogeneity of the properties tensile test samples were taken from minimum section thicknesses of 20 mm and 60mm.

In order to examine the wear resistance of ADI as a wheel material, the test results were compared with those already recorded by the DB AG for conventional wheel/rail steel pairings, which were tested under the same conditions. R7, B6, and HH were all practical application steels for full wheels, wheel rims and rails with carbon contents of 0.5, 0.6, and 0.7 % and (respectively):

ADI/steel pairing showed the most favorable wear characteristics. The austempered ductile cast iron showed less wheel wear and less rail wear for the same test conditions.

At higher contact (normal) forces the favorable influence of the wear systems became more apparent. Mass loss at higher contact forces could be reduced considerably through the use of ADI, especially in the rail sample. The cause of this was primarily the lubricating action of the graphite. The strain-hardening tendency of the austenitic-ferritic matrix structure was also emphasized.

The primary reason for the superior wear resistance of ADI relative to gray cast iron was the strain hardening tendency of the carbon-rich austenite, and the high tensile strength of ADI. The formation of an initial wear maximum on the faster running wheel sample, which coincided with the maximum coefficient of friction, was characteristic of all of the tests.

During the test, the mass loss and the coefficient of friction decreased continually toward a constant (saturation) value. However, with a normal force of 1410 N this saturation value was not achieved with the ADI/900A pairing after 140.000 revolutions. This was explained by the fact that at the lower normal force there was insufficient strain strengthening of the ADI matrix structure on the contact surface. Furthermore, as a result of the lower contact pressure, less graphite was pushed to the surface.

Figure 3 (Madler, 2000) shows the plastically deformed surface regions of the ADI samples, which were stressed under normal forces of 5665 N and 3935 N in the roll wear test. A strain-induced transformation of the austenite to martensite, could not be established in the investigation. However, the graphite nodules were turned in the direction of the loading and showed evidence of plastic deformation. Plastic deformation below the contact surface led to the formation of material "tongues", which propagated inside the samples as cracks. These cracks were recognizable in the ADI samples but to a lesser extent than in the comparable steel wheel samples.

Figure 4 (Madler, 2000) showed that the cracks were regularly intercepted by the deformed graphite nodules. Graphite apparently came through these openings at the sample surface and caused lubrication of the contact area. With increasing pressure, an increase in cracks near the surface was observed in the ADI samples allowing more graphite to reach the contact interface.

The fact that wear characteristics were favorably influenced with higher surface pressures was therefore due to a significant strengthening of the surface (or tread) of the ADI sample, and by the greater lubrication in the boundary layer between both friction partners, which was missing in the pure steel pairing. The rail steel samples in contact with the ADI showed fewer cracks, leading to lower wear on the rail sample. The lower wear on the ADI wheel material was not compensated for by a higher wear on the rail material. Still further pursuit of the project was needed.

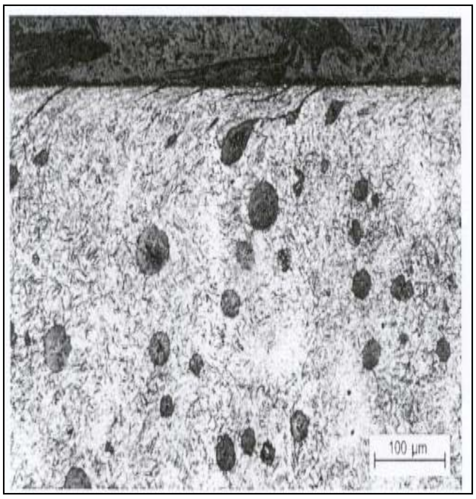

Figure 3. Surface microstructure of the ADI test sample after roll / slip testing at F_N = 3935 N (Madler, 2000)

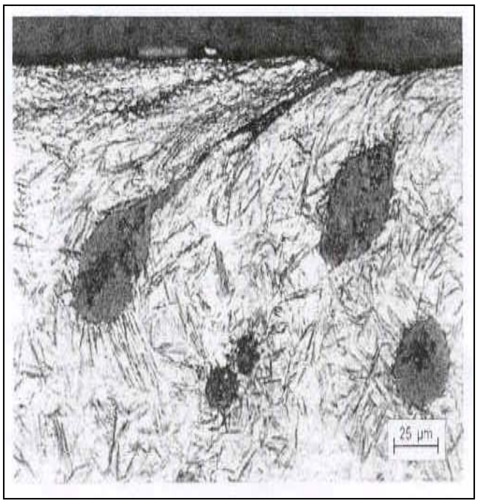

Figure 4. Surface microstructure of the ADI test sample after roll / slip testing at F_N = 5665 N (Madler, 2000)

2. CONCLUSION

In spite of the references of the Finnish, German and Japanese railway associations many practical tests are still needed to benefit from ADI as an alternate material for railcar wheel sets.

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