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Investigating Coupler Knuckle Performance

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Summary

In January 2004, the Association of American Railroads (AAR) initiated a new program to investigate improved materials for coupler knuckles. This initial effort, conducted by Transportation Technology Center, Inc. as part of the AAR's Strategic Research Initiative, was launched in response to several railroads' experiences with premature knuckle failure caused by fatigue.

Data from one U.S. railroad indicated that factors other than material type/properties played a part in fatigue-induced failure. In the near term, significant gains in knuckle fatigue performance can be achieved by focusing on obtaining the production quality specified in Specification M-211 of the AAR's *Manual of Recommended Standards and Practices.*

Issues such as solidity, surface finish, and correct heat treatment can be controlled to provide a knuckle that may meet the industry's current needs. Following a more rigorous inspection process in the supply chain, the industry can then investigate if the current design is compatible with the longitudinal service environment.

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INTRODUCTION AND CONCLUSIONS

In January 2004, the Association of American Railroads (AAR) initiated a new program to investigate improved materials for coupler knuckles. This initial effort, conducted by Transportation Technology Center, Inc. (TTCI) as part of the AAR's Strategic Research Initiative, was launched in response to several railroads' experiences with premature knuckle failure caused by fatigue. As part of this effort, two Class I railroads were contacted. Results from one of the railroads, Norfolk Southern Corporation (NS), are reported herein.

Under normal railroad operations, a coupler knuckle is expected to survive an ultimate draft load of 650,000 pounds. The knuckle acts like a fuse that protects the rest of the draft system. Qualification testing requirements in Specification M-211 of the *AAR Manual of Standards and Recommended Practices* (MSRP) mandate that the knuckle must not take a permanent set of more than 0.03 inch at a load of 400,000 pounds. Specification M-211 has requirements for ultimate strength but does not address fatigue. To date, there are no laboratory tests or performance specifications that provide a fatigue life requirement for knuckles. This *Technology Digest* discusses experiences from railroads and the gains that can be realized by ensuring knuckles meet the current Specification M-211 specification. Additional work could be performed that would facilitate the inclusion of a fatigue life performance specification and/or tighten existing Specification M-211 production requirements.

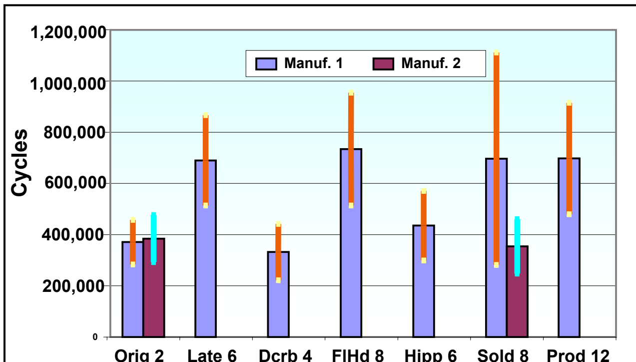
NORFOLK SOUTHERN'S EXPERIENCE

In the early 1990s, NS began a research effort to determine the cause of frequent knuckle failures due to fatigue. Several years of research culminated in the development of a test rig and inputs that allowed NS a more controlled environment for testing knuckles. Figure 1 is a photograph of the NS test rig.

Figure 1. Test Rig used to Test Knuckles at Norfolk Southern

The evolution of this laboratory test process is documented in T.W. Ward's 1992 American Society of Mechanical Engineers paper.[1] The challenge was to create a laboratory test environment that yielded knuckle failures with characteristics similar to those seen in the field. Following verification of the laboratory testing method, NS conducted years of research on knuckles from multiple suppliers through several production dates. In addition, some manufacturers provided knuckles with unique materials and production methods that were compared to the current knuckles.

Figure 2 provides a comparison of the fatigue performance for knuckles produced using current manufacturing methods. The left y-axis shows the average cycles to fatigue failure that knuckles experienced. The error bars on each bar document the standard deviation of the sample. In addition, each reference has a number following it that documents the number of knuckles in the sample. The first two blue bars and the last blue bar ("orig," "late," and "prod") represent typical E knuckle production with the "orig" (original) being the beginning of the test program. As manufacturers and railroads paid more attention to the quality of the product, the average number of cycles to failure nearly doubled (compare to "late" and "prod" (later and production).



Orig = Initial Test
Late = Testing 1 year later (product quality monitored)
Dcrb = De-carburized knuckles
FlHd = Flame hardened knuckles
Hipp = Hot isostatic pressed knuckles
Sold = High solidity knuckles
Prod = Knuckles selected from standard production (product quality monitored)

Figure 2. Data from NS Test Laboratory of Various Knuckles

As also shown in Figure 2, several other manufacturing techniques — flame hardening, and hot isostatic pressing (HIPP) — have been attempted. Following the evaluation of the HIPP knuckles the mechanism of fatigue failure was thought to be decarburization. To test this theory NS requested some specially manufactured knuckles that were decarburized. The decarburized knuckles performed poorly in lab fatigue testing as demonstrated in Figure 2, therefore NS concluded this was the mechanism that did not allow HIPP manufactured knuckles to have satisfactory fatigue life performance. The flame hardening process was only successful in this data set, but not so in other attempts. With flame hardening, the difficulty in preventing undesirable internal stresses in the heat affected regions is an issue.

In addition, to the processes discussed, a carbon fiber knuckle design was tested, but did not perform well.

Casting Quality Specified by the AAR

Based on the data provided by NS, it can be concluded that a significant gain was made in the fatigue life of the knuckle evaluated when the quality of the product was monitored. The AAR *Manual of Standards and Recommended Practices* (MSRP) Specification M-211 controls the quality of all cast products related to the longitudinal buff/draft system. The following are examples of products tested and the specifications related to the expectation.

Figures 3 and 4 (coupler with shot peen in void) show an extreme example of an internal void, which occurs in a critical area on the knuckle. Specification M-211, pages B-61, 63, provide examples of maximum shrinkage (use in conjunction with table on page B-20 and sectional diagram on page B-43). Figure 5 is an example of the maximum shrinkage allowed for a critical region on the knuckle. When compared to Figures 3 and 4, it is clear that the minimum quality requirement is not always being met.

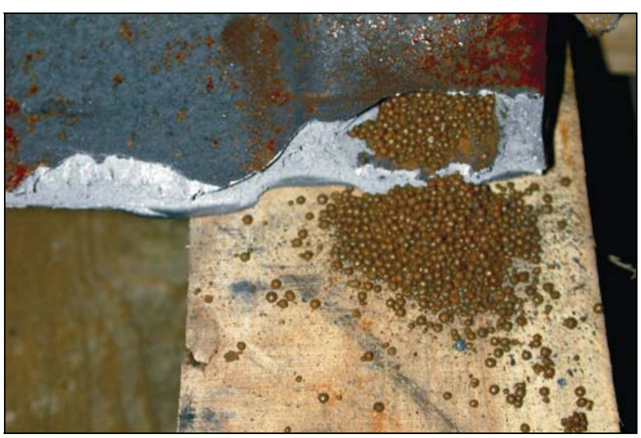


Figure 3. Void in Knuckle Casting Filled with Shot Peen

Figure 4. Sample Knuckle Tested at NS, Large Void in Casting

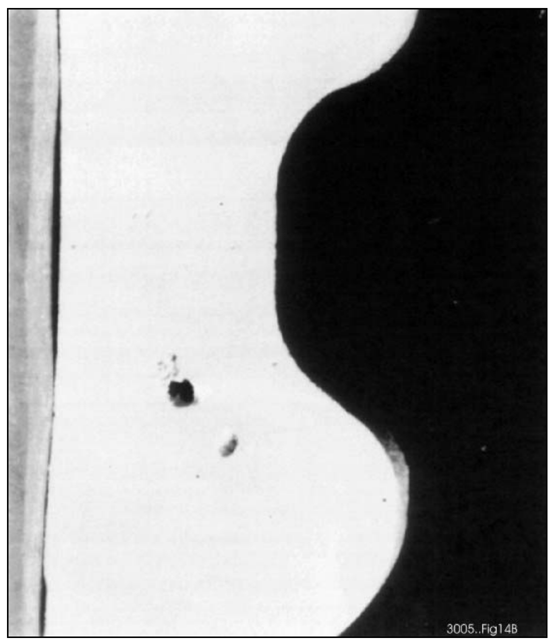


Figure 5. Sample of Maximum Shrinkage (Level 4) Allowed in Critical Region of a Knuckle

Section 13.2 of Specification M-211 also refers to the Steel Castings Research and Trade Association (SCRATA) *Comparators for the Definition of Surface Quality of Steel Castings*.[2] These criteria reference limits for items such as porosity, surface inclusions, scabs, and mechanical dressing (grinding). The AAR recently acquired a set of comparators, which define all the above requirements. For example, in a critical region of the knuckle (the pulling face) a limit of B2 is specified for surface inclusions in the SCRATA comparator. In Figure 6 a scan from the SCRATA comparator is shown that indicates the allowable level of surface inclusions. This can be compared to the knuckle shown in Figure 7. There is reliable evidence to indicate the failure was initiated by substandard surface quality.

Figure 6. SCRATA Comparator for Surface Inclusions Level B2 as Stated in AAR M-211

Figure 7. Surface Inclusions from a Knuckle that Experienced Premature Fatigue Failure

Regular inspection is the most effective contributor to longer knuckle fatigue life. The AAR conducts inspections and compliance tests of all certified foundries worldwide. These inspections do not include an evaluation of product quality; rather, they serve to ensure that each foundry has in place all the necessary tools and procedures to meet AAR specifications and certification requirements. Currently, product quality assurance is the responsibility of the purchaser. Specification M-211 does provide procedures for the acceptance of castings and specifies the right of the buyer to inspect the process while their contract is being fulfilled (see M-211, Section 14.0).

CONCLUSION

In the near term, periodic sampling and inspection ensures that knuckle quality has met AAR Specification M-211 and results in better knuckle life. More stringent requirements are a good starting point necessary to keep knuckles from premature fatigue failure for longer trains and more powerful locomotives. Once a method is established to ensure/improve the supply of quality castings that meet AAR requirements, additional efforts may be necessary to ascertain the appropriate design in the current railroad environment.

References

1. Ward, T.W., 1992, "An Approach to Testing Draft System Components," Proceedings, RTD-Vol. Vol. 5 – Rail Transportation, American Society of Mechanical Engineers, 1992.
2. *Comparators for the Definition of Surface Quality of Steel Castings,* Steel Castings Research and Trade Association, 1981.