ASME STANDARDS
TECHNOLOGY, LLC

STP-PT-086

# EFFECTS OF HIGH TEMPERATURES AND FIT-UP OF RIVETED JOINTS ON STEEL RIVETS

STP-PT-086

# Effects of High Temperatures and Fit-up of Riveted Joints on Steel Rivets

*Prepared by:*

Linn Moedinger – Strasburg Railroad Company
George W. Galanes, P.E. – Diamond Technical Services, Inc.

ASME STANDARDS TECHNOLOGY, LLC

Date of Issuance: October 2, 2017



ASME Standards Technology, LLC
Two Park Avenue, New York, NY 10016-5990

ISBN No. 978-0-7918-7194-2

## TABLE OF CONTENTS



## LIST OF FIGURES



## LIST OF TABLES

## FOREWORD

The purpose of this project is to evaluate the effects of driving temperature and fit-up on steel rivets used in boiler construction. There has been conflicting information as to the maximum driving temperature for hot riveting of steel rivets used in boiler construction. Strasburg Railroad Company was the project coordinator and provided a series of hot driven rivets after receiving funding from ASME-ST-LLC. Strasburg contracted the metallurgical testing of the rivets to Diamond Technical Services, Inc.

Both Strasburg Railroad Company and Diamond Technical Services, Inc. would like to acknowledge ASME for funding this entire project.

Established in 1880, the ASME is a professional not-for-profit organization with more than 135,000 members and volunteers promoting the art, science and practice of mechanical and multidisciplinary engineering and allied sciences. ASME develops codes and standards that enhance public safety, and provides lifelong learning and technical exchange opportunities benefiting the engineering and technology community. Visit https://www.asme.org/ for more information.

ASME ST-LLC is a not-for-profit Limited Liability Company, with ASME as the sole member, formed in 2004 to carry out work related to new and developing technology. ASME ST-LLC's mission includes meeting the needs of industry and government by providing new standards-related products and services, which advance the application of emerging and newly commercialized science and technology, and providing the research and technology development needed to establish and maintain the technical relevance of codes and standards. Visit http://asmestllc.org/ for more information.

## SUMMARY

This study evaluated the maximum hot rivet driving temperature, and the effects of plate fit-up, rivet hole clearances and joint tightness on rivet steel properties. The most urgent need was to establish whether heating rivets to 2250 degrees F (1230 degrees C) for driving had a detrimental effect on final steel rivet properties compared with steel rivets heated at 1950 degrees F (1065 degrees C). The 1950 degrees F (1065 degrees C) maximum rivet driving temperature was evaluated in a previous, privately funded study, however the scope of that study was focused only on temperature.

This study focused on the two temperatures previously mentioned, but added additional physical properties to the test plates for consideration outside recommended parameters for standard hot riveting. These anomalies included oversizing rivet holes, poor plate fit-up with springback, and soaking rivets at the higher temperatures 1950 degrees F and 2250 degrees F (1065 degrees C and 1230 degrees C) for extended periods (10 minutes and 20 minutes) before driving into the test plates.

The steel rivets for this project were supplied from ASTM A675 carbon steel bar, 7/8-inch diameter. A pneumatic hammer was used to drive the 7/8-inch (22-millimeter (mm)) diameter rivets into button head style heads after heating to the designated metal temperature for hot forming. Heating of rivets was performed using electric resistance heating and a gas fired furnace. Three test conditions were performed.

Under the first test condition, carbon steel test plates were prepared with rivet holes 1/8-inch (3.2 mm) oversized, to see if the additional upsetting of the rivet to fill the larger holes was detrimental to the finished product.

The second test condition used carbon steel test plates with holes 1/16-inch (1.6 mm) oversize (normal) to simulate the situation where plates are not tightly fit together, thus allowing the plates to spring-back during hot riveting. This test was in response to a specific report in an early study that indicated this cyclic compression/stretch during driving created a sub-par finished rivet.

The third test condition dealt with carbon steel test plates with 1/16-inch (1.6 mm) oversized holes that were tightly held together. In addition, during the third series of tests, the rivets were held for 10 minutes and 20 minutes at metal temperature before driving.

Each rivet was carefully extracted from the carbon steel test plates with the material subjected to the following metallurgical lab tests: macro-photographs of extracted rivets, tensile testing using sub-size tensile specimens, hardness testing, and metallographic examination.

The results of this study revealed the maximum driving temperature can remain at 2250 degrees F (1230 degrees C) under the 2017-edition of the ASME Boiler and Pressure Code (BPVC), Section I, Part PL. Metallurgical testing concluded that the rivets after hot driving increased in strength with slightly increased ductility. The increase in ultimate tensile strength and yield strength most likely occurred from two metallurgical factors; the first was dynamic recrystallization during hot riveting and transformation products which formed in the rivet steel microstructure upon cooling.

Overall, the effects of oversized plate holes, plate tightness and extended soak time (20 minutes) did little to change the result of increased tensile properties and improved ductility for the hot driven rivets. The rivets driven at 1950 degrees F (1065 degrees C) or 2250 degrees F (1230 degrees C) into oversized holes, with plate spring back and a soak time of up to 20 minutes before hot riveting showed no detrimental phases or anomalies.

# 1 INTRODUCTION

The objective of this study was to evaluate the effects on rivet properties based on maximum hot rivet driving temperatures, plate fit-up, rivet-hole clearances and joint tightness. The most urgent need was to establish whether heating rivets to 2250 degrees F (1230 degrees C) for driving had a detrimental effect on final rivet mechanical properties compared with rivets heated at 1950 degrees F (1065 degrees C). At present, the 2017 Edition of the BPVC, Section I [(1)] has limited the maximum temperature for hot riveting to 2250 degrees F (1230 degrees C). However, this maximum driving temperature has been challenged by others in the past who have maintained the maximum temperature should be 1950 degrees F (1065 degrees C).

This study focused on the two temperatures previously mentioned, but added additional variables to the test plates for consideration outside recommended parameters for standard hot riveting practices. These variables included oversizing rivet holes, poor plate fit-up using spring back, and soaking rivets at the higher temperatures 1950 degrees C and 2250 degrees F (1065 degrees C and 1230 degrees C) for extended periods (10 minutes and 20 minutes) before driving into the test plates.

To accomplish the objective, it was decided to simulate riveting of locomotive boilers by using carbon steel test plates 4-inches (102 mm) by 20-inches (508 mm) by ¾-inch (19 mm) in thickness with pre-drilled holes to accommodate carbon steel rivets. The rivets for this entire project were supplied from ASTM 675 carbon steel bar, 7/8-inch in diameter. A pneumatic hammer was used to drive the 7/8-inch (22 mm) diameter rivets into button head style heads after heating to the designated metal temperature for hot forming. Heating of rivets was performed using electric resistance heating and a gas fired furnace. Three test conditions were performed;

The first test condition used carbon steel test plates which were prepared with rivet holes 1/8-inch (3.2 mm) oversized, to see if the additional upsetting of the rivet to fill the larger holes was detrimental to the finished steel rivet mechanical properties.

The second test condition used carbon steel test plates with holes 1/16-inch (1.6 mm) oversized (normal) to simulate the situation where plates are not tightly fit together, thus allowing the plates to spring-back during hot riveting. This test was in response to a specific report in an early study that indicated this cyclic compression/stretch during driving created a sub-par finished rivet.

The third test condition dealt with carbon steel test plates with 1/16-inch (1.6 mm) oversized holes that were tightly held together. In addition, during this third series of tests, the rivets were held for 10 minutes and 20 minutes at metal temperature before driving. A complete spreadsheet summarizing the metallurgical lab tests is shown in Table A1 in Appendix A.

A fourth test had been in the original test program where hand riveting is accomplished using hand hammers with no pneumatic or hydraulic assistance. While this may be done on a very limited basis for historical purposes, the scope of its use in Test 4 did not seem relevant enough to justify the expenditure given limited budget constraints.

Upon completion of riveting by Strasburg Railroad, the hot riveted carbon steel test plates were sent to a metallurgical lab under the direction of DTS Metallurgical. Each rivet was carefully extracted from the carbon steel test plates with the material subjected to the following metallurgical lab tests; macro-photographs of extracted rivets, tensile testing using sub-size tensile specimens, hardness testing, and metallographic examination.

## 2 BACKGROUND

Over the years when hot riveting was the primary method used in joining plates and support structures for locomotive boilers, many different practices were employed and in later years, various studies were conducted to determine the effects on the end product. Additionally, with the decline of riveting in mainstream boiler manufacturing, there has been considerable "technological whisper down the lane". In both cases, previous studies and urban myths tended to contradict one another.

A literature review revealed several interesting technical papers on the subject of elevated temperature effects on rivet properties from the 1920s to 1930s. The first publication was a study that attempted to show that high temperature hurt rivets [2]. It was concluded in this article that carbon steel rivets heated to above a critical temperature 1950 degrees F (1065 degrees C) will result in significantly reduced ductility. Also, hot riveting at temperatures above 1950 degrees F (1065 degrees C) in conjunction with vibratory stresses from poor plate fit-up result in rivets breaking while driving or shortly thereafter.

Another similar publication [3] dealt with structure and strength of overheated rivet steel. For this particular article, a study conducted on industrial quality carbon steel rivets when heated until sparking resulted in significantly reduced ductility at 4.0 percent and reduction of area at only 10.8 percent. No mention was made of the spark emitting temperature. Also, this temperature was not investigated for this study.

One of the more recent publications which had been reviewed concerned the impact of hot driving process on the strength and ductility of steel rivets [4]. This publication closely relates to the current test program performed on steel rivets. The conclusion from this study parallels what was observed in that heating the rivets to 2250 degrees F did not degrade strength nor ductility. In fact, the paper cites an increase in ultimate tensile and yield strength values of hot driven rivets over original steel rivet properties compared at room temperature. The ductility also increased resulting in a stronger rivet with adequate ductility. The cause of the strength was not specifically addressed but was suggested as being from dynamic recrystallization and transformation products upon cooling.

A publication in the *National Board Bulletin* [5] provides an excellent background into installation of boiler rivets and recommendations associated with the installation techniques.

Other publications that were reviewed related to tensile testing of rivets joints conducted in 1930 by the University of Illinois at Champaign [6]. The concern was how to evaluate tensile loads on completed riveted joints, which in some applications tensile loads are not adequately designed for in service.

While it is not likely that riveted construction of boilers will return to the mainstream any time soon, riveted repairs are performed routinely and partially riveted new boilers are still constructed. It is hoped these tests will provide the necessary guidance in drafting technically correct guidance and rules in the BPVC.