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# The Mechanical Properties of 36Ni Alloy Filler Metals for Cryogenic Pipeline Applications

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## Abstract

Plate butt welds have been produced from a wide range of commercially-available 36Ni-based filler metals to examine the mechanical properties of the resulting weldments.

36Ni alloy (36%Ni-bal.Fe) possesses a very low coefficient of thermal expansion (CTE) of 1.7 x $10^{-6}$m/m/$^{o}$C – approximately ten times lower than stainless steel – which makes the alloy very attractive for cryogenic applications. Construction of cryogenic pipelines with 36Ni alloys could allow elimination of expansion loops and bellows, which are required to reduce thermal stresses induced during operation when constructed with stainless steel. Historical application of this alloy to cryogenic applications in the petroleum industry has been limited to tank lining in liquefied natural gas (LNG) tankers and limited small scale piping (Ref 1). To date, 36Ni as an alloy has seen very limited use in pipeline and load-bearing applications due to a perceived difficulty in producing welds of sufficient strength.

Filler wires designed to match the CTE of 36Ni base metal tend to have low mechanical strength values when compared with the wrought base metal. Attempting to overcome this strength decrease, weld consumable suppliers have produced alloyed filler metals with a moderate increase in CTE value but produce significantly higher mechanical strengths than the matching filler metals. In this work, welds were made with commercially-available matching CTE and alloyed filler metals to test the yield strength, tensile strength, and impact toughness of the resulting weldments. To cover both construction and operation temperatures of LNG pipelines, tensile tests were performed at both room and cryogenic temperatures.

This study provides an overview of mechanical properties for commercially-available filler metals for 36Ni alloy construction. This materials survey provides information for determining loading limits and performance capabilities of various filler metals available for 36Ni alloy construction.

## Introduction

For LNG loading terminals, a driving force exists to change loading pipeline design from the standard jetty-based stainless steel to a sub-sea 36Ni alloy-based design. By changing pipeline materials from stainless steel to a 36Ni alloy, the jetty structure and expansion loops can be eliminated in favor of a straight sub-sea pipeline, thus decreasing the materials required, reducing environmental disturbance, and increasing the security of the pipeline. These improvements are facilitated by the 36Ni's low CTE, which is approximately 10 times lower than that of stainless steel. The low CTE value decreases thermal stresses that arise when the pipeline is cooled from ambient to operating temperature. Traditional LNG offloading lines compensate for these thermal stresses by including mechanical expansion loops and bellows that can deflect with the thermal stresses. Operating expenses of the LNG offloading facility can be reduced as well by lengthening the LNG pipeline to deeper water, reducing the amount of any required loading berth access dredging. Development of 36Ni as a pipeline material is still ongoing. A critical component of this work is determining a proper weld filler metal for both pipe construction in the mill and pipeline installation in the field that can withstand the stresses imparted from installation and service. This work aims to find an existing filler metal class that meets these needs.

Five commercially-available weld filler wires were selected for this study as listed in Table 1. These filler wires fall into two general categories: (1) matching CTE properties, and (2) enhanced mechanical properties. The matching CTE filler metals are designed to match the base metal chemistry (36%Ni/bal.Fe) and thus the base metal CTE. The enhanced mechanical property filler metals are designed with added alloy elements to improve mechanical strength but also increase the CTE. The matching CTE filler metals were designed for applications where CTE matching with the base metal is critical. The enhanced mechanical property filler