ORNL Manufacturing Demonstration Facility
Technical Collaboration **Final Report**

MAGNETIC PROCESSING OF STRUCTURAL COMPONENTS FOR TRANSPORTATION VEHICLES

Metalsa Roanoke, Inc.

Project ID: MDF-UP-2013-06
Start Date: January 15, 2013
Completion Date: September 30, 2017
Company Size: Large business, >250 employees

Summary

The goal of this project was to investigate the effect of the application of magnetic fields during tempering of low alloy 1125 steel to determine the effect on the mechanical properties of the samples and to determine the energy efficiency benefits of tempering under a magnetic field. ORNL processed two sets of samples for this project. The first set of samples was determined by Metalsa to be lacking the austenitization step that should have preceded tempering. The second set of samples processed by ORNL was shipped to Metalsa, but cannot now be located. Without mechanical property data or characterization of properly processed samples the effects of the magnetic processing cannot be determined. This report captures the critical experimental conditions for the ORNL aspect of this research in case those samples are found and can be tested.

Background

This phase 1 technical collaboration project (MDF-TC-2013-004) was begun on January 15, 2013 and was completed on September 30, 2017. The collaboration partner Metalsa Roanoke Inc. is a large business.

ORNL researchers were the first to demonstrate High Magnetic Field Processing (HMFP) as a revolutionary materials processing technology that significantly influences the microstructure, kinetics and mechanical performance of many materials at the nano-scale. Metalsa was interested in developing this HMFP technology with ORNL for improving the strength of the side-rails that Metalsa currently manufactures for approximately 150,000 trucks in the heavy truck industry in North America. These side-rails form the central part of the chassis of a heavy truck, and work under demanding conditions. Consequently, strength and durability are considered important properties by original equipment manufacturers (OEMs). Metalsa Roanoke Inc. is also concerned with improving the energy efficiency of both their manufacturing process and the final product performance. Most vehicle manufacturers focus on using lightweight (resulting in weight reduction), high performance materials to improve energy efficiency. However, reducing the cost of production is also important, since the manufacture of lightweight high strength steels involves high levels of energy consumption during heat treatment.

Metalsa Roanoke Inc. aimed to develop a manufacturing process which allows the production of weight-reduced side-rails through a more energy-efficient production processing method. Metalsa staff anticipated that the use of magnetic fields would reduce the energy demand for heat treatment, resulting in more energy efficient manufacturing processing. In addition, manufacturing lighter side-rails would contribute to the DOE´s goal of making trucks more energy efficient.

This ORNL technical collaboration leveraged previous work between ORNL and Metalsa to evaluate the effect of magnetic processing to improve the tempering cycle in the manufacture of side-rails for heavy trucks; and to demonstrate the applicability of this technology as an option to save energy and improvement of mechanical properties in the final product. The following are part of the conclusions from that earlier effort:

1.) Thermomagnetic processing was shown to make significant simultaneous improvements in yield strength and ultimate tensile strength with no loss of ductility for the truck rail application.
2.) Improvements in the ultimate tensile strength and yield strength in the range 20 to 30% were measured on the lower hardenability, 1125 low alloy steel test samples. For these experiments, using only a conventional austenitization and quench heat treatment (no magnetic field), the alloy samples received only a 1 Tesla tempering treatment at a tempering temperature that was 150°C lower than their current process temperature of 450°C and for a brief tempering time of 5 minutes. This time was just 20% of the temper heat treatment time required in their current process at the higher temperature. Significant energy savings and improved production process efficiency are viable under these new conditions.

Technical Results

For this Phase 1 MDF technical collaboration a parametric study evaluating the effects of several low magnetic field strengths at different tempering temperatures for short time intervals was conducted to optimize the process for potential commercial implementation. Since only tempering heat treatments were to be investigated, Metalsa staff were to provide the 1125 low alloy steel tensile sample blanks in the already austenitized and quenched condition which would be mean they would require only tempering in the ORNL magnetic facility. The test conditions are summarized below.

The experimental conditions are defined here:

- Samples processed at 0, 1, and 3 Tesla field.
- Tempering temperature/time combinations evaluated were 100°C/15 min., 200°C/15 min., 400°C/ 1 min., and 600°C/1 min.
- Induction heating was accomplished using an induction heating coil surrounding a 1-inch" long hollow graphite susceptor to achieve temperature uniformity along the length of the samples.
- A 2 kilowatt induction power supply was employed with an operating frequency of 150kHz-450khz.
- Samples processed between 320kHz-370kHz.
- An argon cover gas was used on all tests.
- Three samples were processed for each condition described above

The nominal chemistry range for the 1125 low alloy steel is given in Table 1 in weight percent.

Table 1 Nominal chemistry (in weight percent) for the 1125 truck rail steel alloy

C	Mn	P	S	Al	Si
0.20-0.26	1.00-1.35	0.025 max	0.015 max	0.020-0.070	0.10-0.30

The first batch of magnetically processed samples was provided to Metalsa for hardness testing. From this testing Metalsa realized from the extremely low hardness values that the prior austenitization and quench heat treatment needed for the samples had not occurred before the samples had been shipped to ORNL for the HMFP tempering step. Figure 1 shows some of the 36 specimens provided to Metalsa in batch one.

Figure 1 Part of the first series of HMFP samples that inadvertently did not get the prior austenitization and quench heat treatment at the industrial partner's facility before receiving the subsequent HMFP tempering treatment at ORNL.

The lack of the prior austenitization and quench heat treatment on the first batch required that a second series would need to be processed by ORNL. For the second series, instead of just providing cylindrical blanks those specimens were rough machined into small round tensile bars for ease of testing subsequently. An example of one of those second series specimens with two thermocouples attached to either end of the test coupon to monitor and record actual temperature during the HMFP experiments, is shown in Figure 2.

Figure 2 An example of the replacement rough machined, austenitized and quenched tensile couples used for the second series of HMFP parametric study experiments.

For batch 2, Figures 3 through 14 document the HMFP experiments on batch two samples demonstrating the samples were uniform in temperature throughout the runs (TC1 and TC2 thermocouple data are essentially identical), indicate the induction power required, and show the transient time at temperature profiles for the specified experimental parameters at the top of each figure.

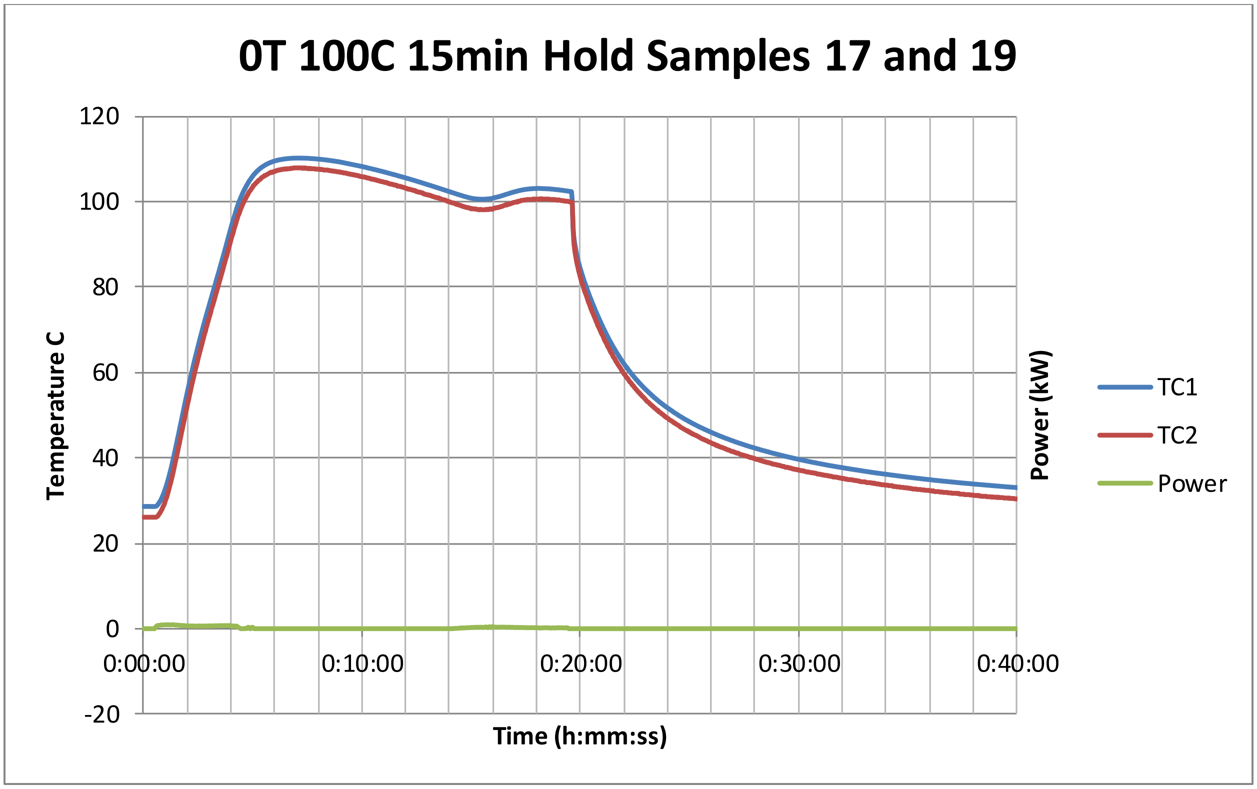

Figure 3 Experimental run data for the 0 T, 100°C/15 min. hold experiments

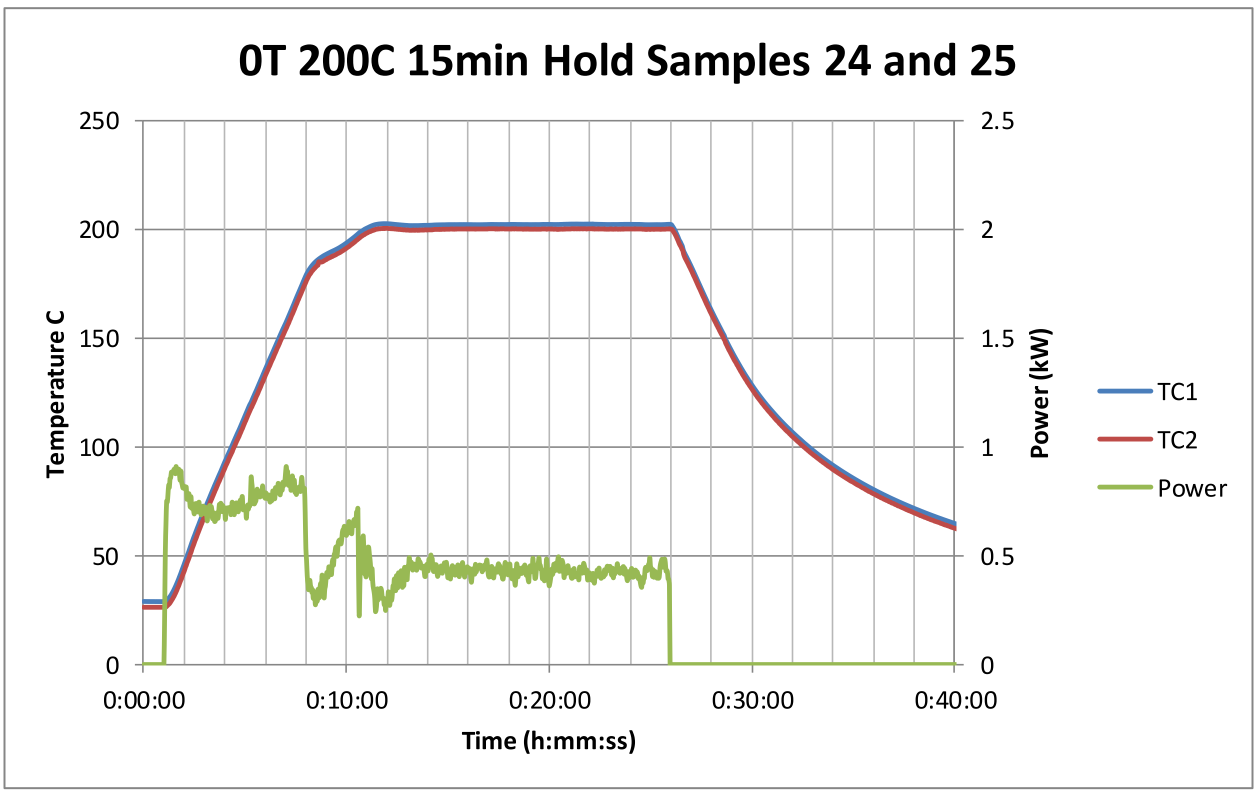

Figure 4 Experimental run data for the 0 T, 200°C/15 min. hold experiments

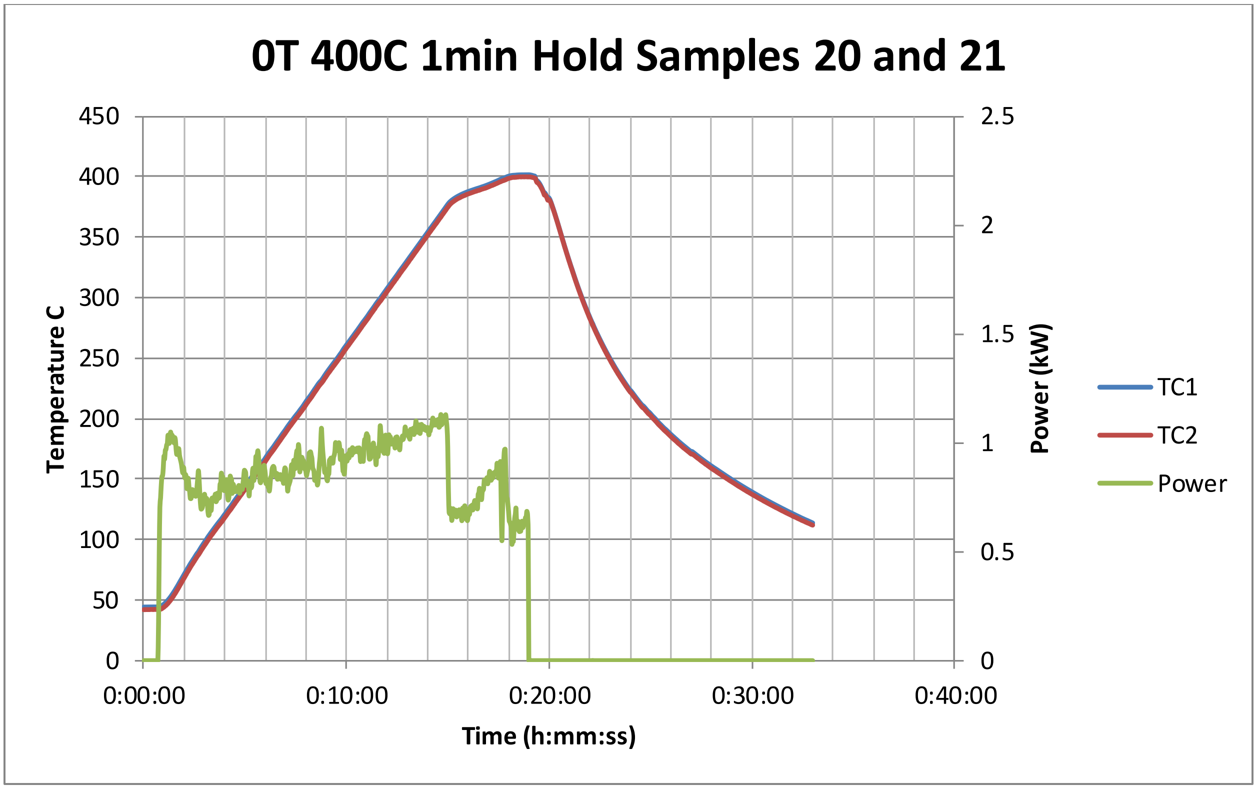

Figure 5 Experimental run data for the 0 T, 400°C/1 min. hold experiments

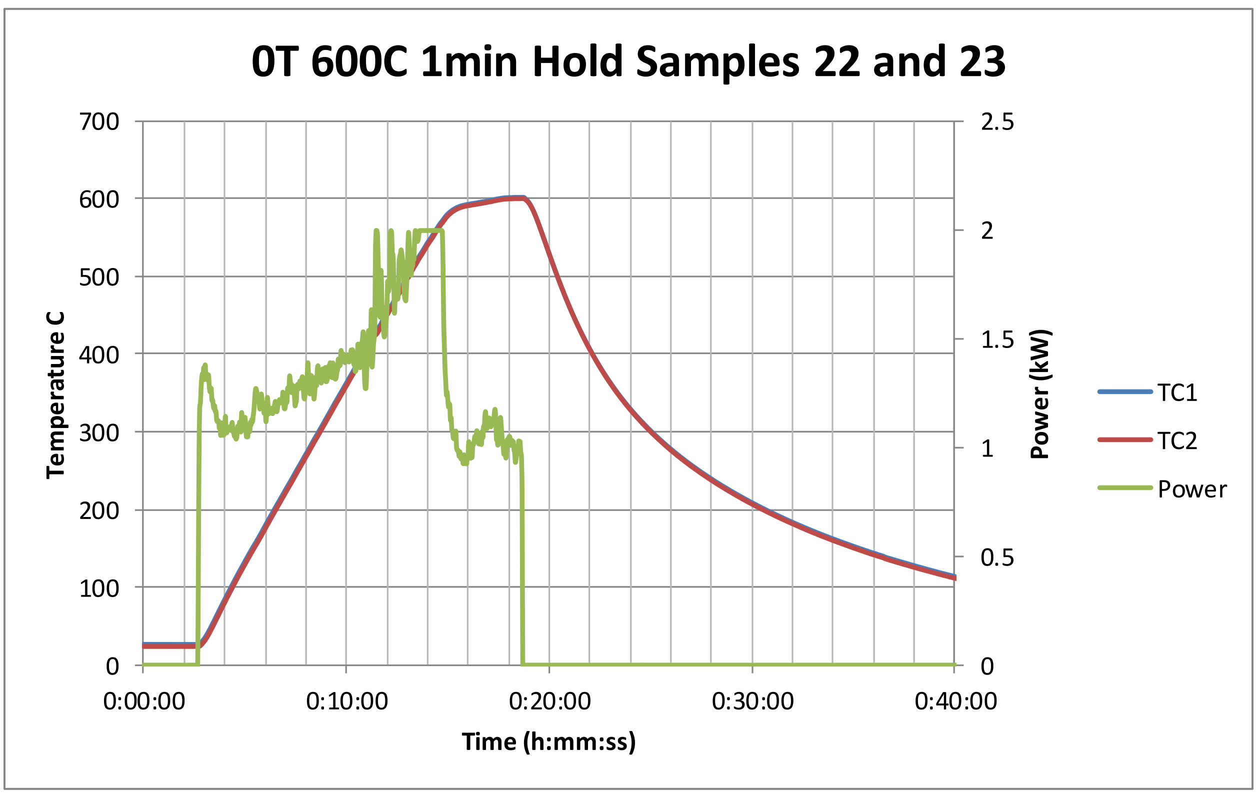

Figure 6 Experimental run data for the 0 T, 600°C/1 min. hold experiments

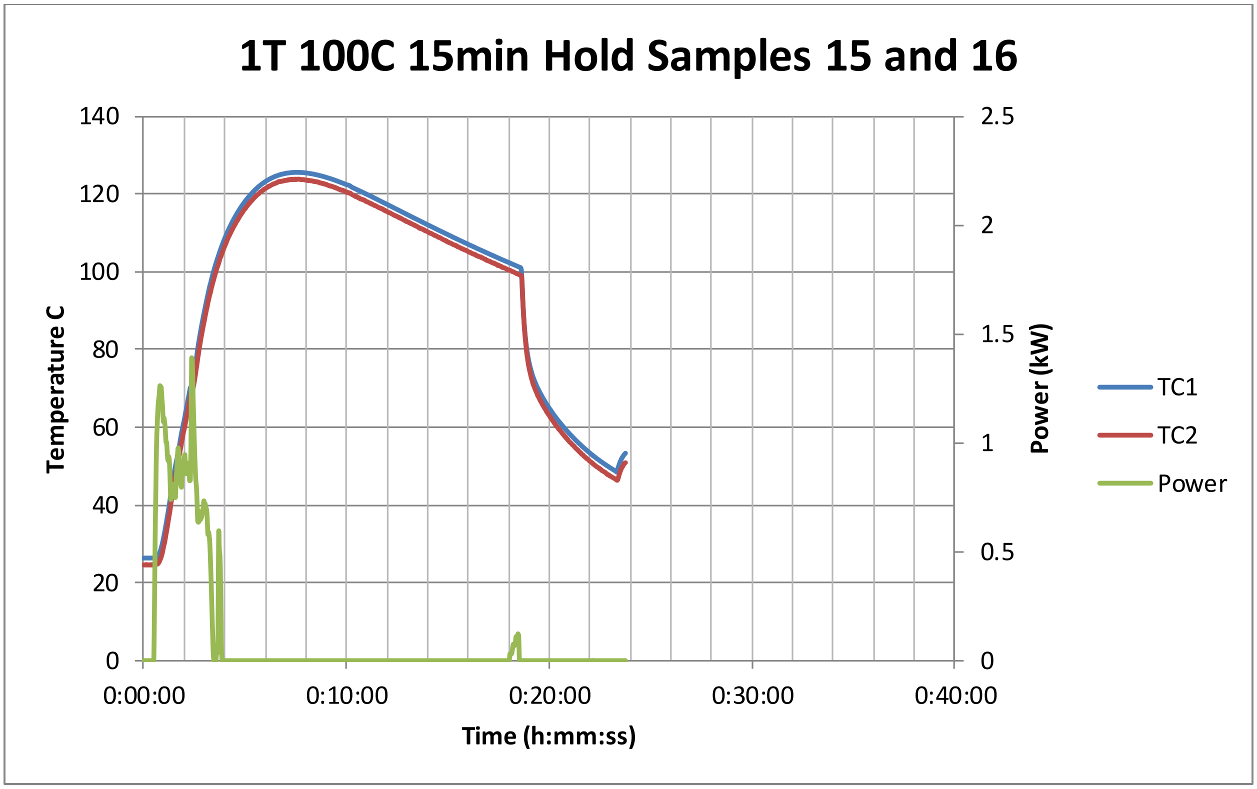

Figure 7 Experimental run data for the 1 T, 100°C/15 min. hold experiments

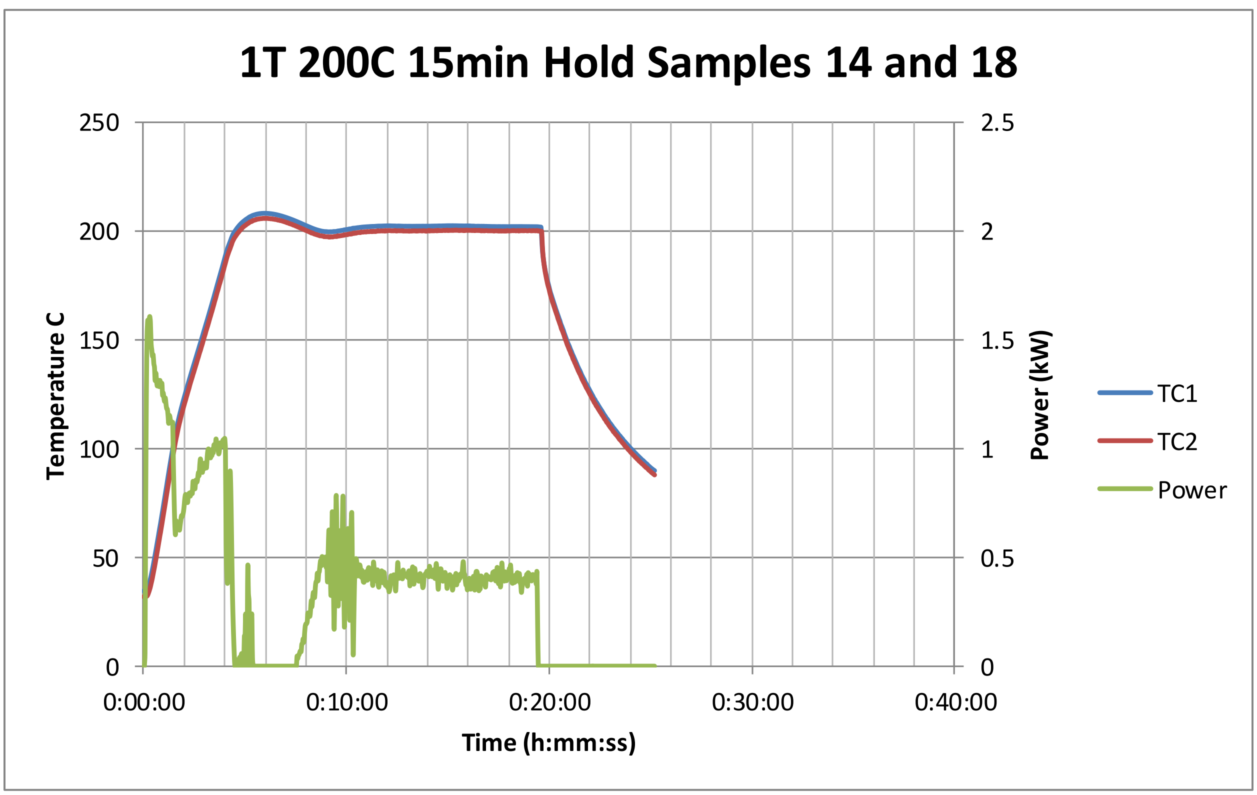

Figure 8 Experimental run data for the 1 T, 200°C/15 min. hold experiments

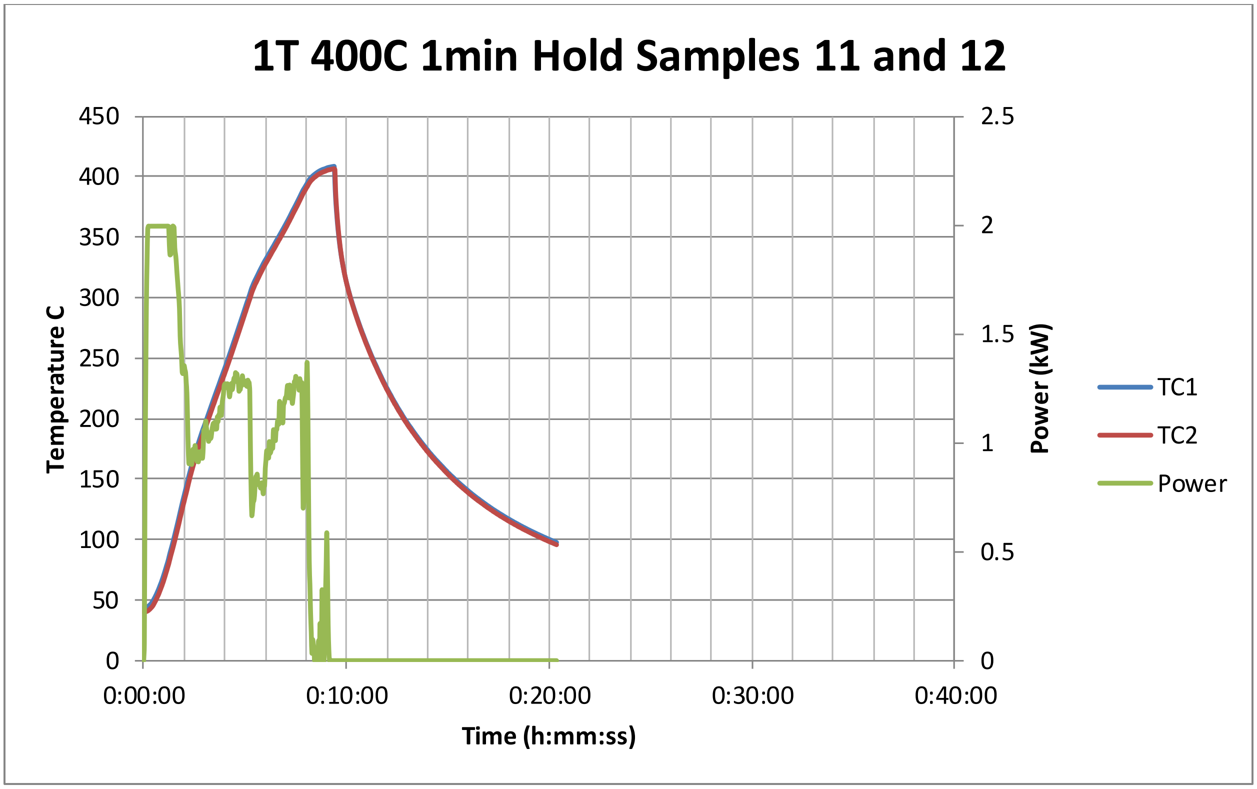

Figure 9 Experimental run data for the 1 T, 400°C/1 min. hold experiments

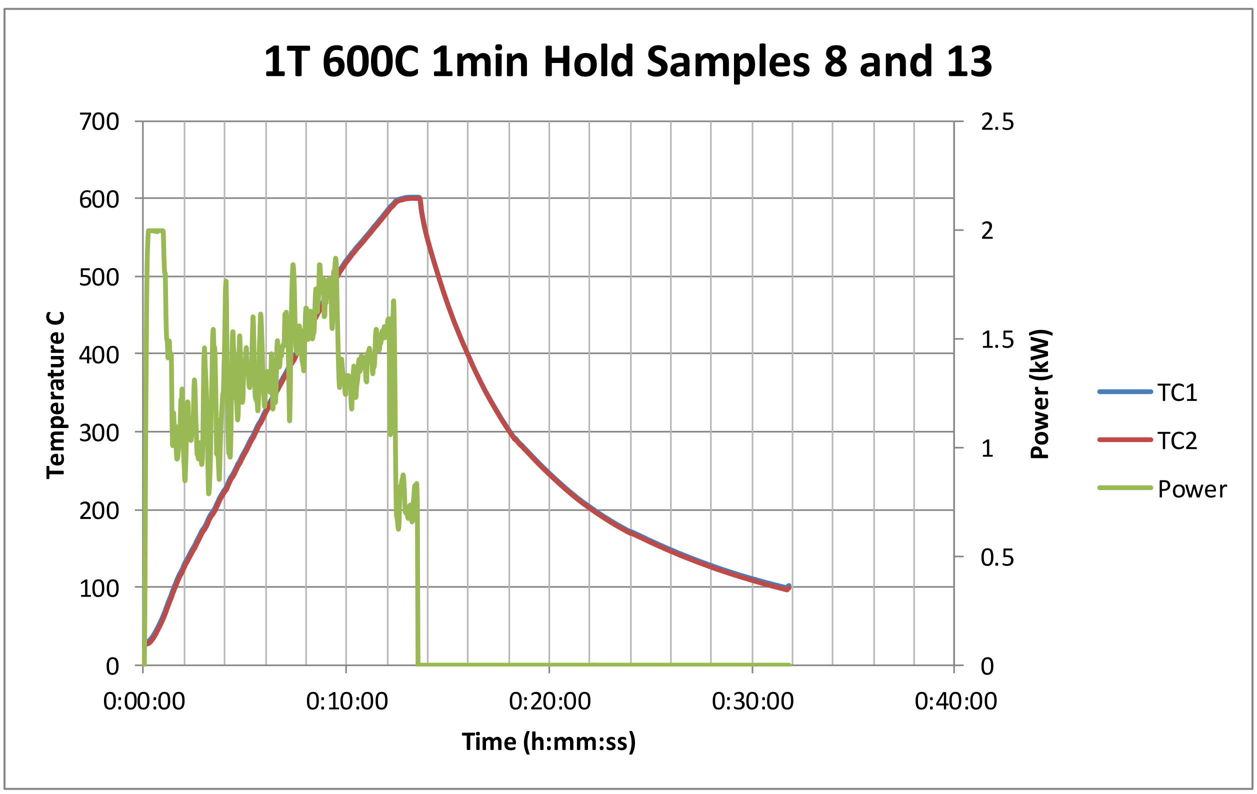

Figure 10 Experimental run data for the 1 T, 600°C/10 min. hold experiments

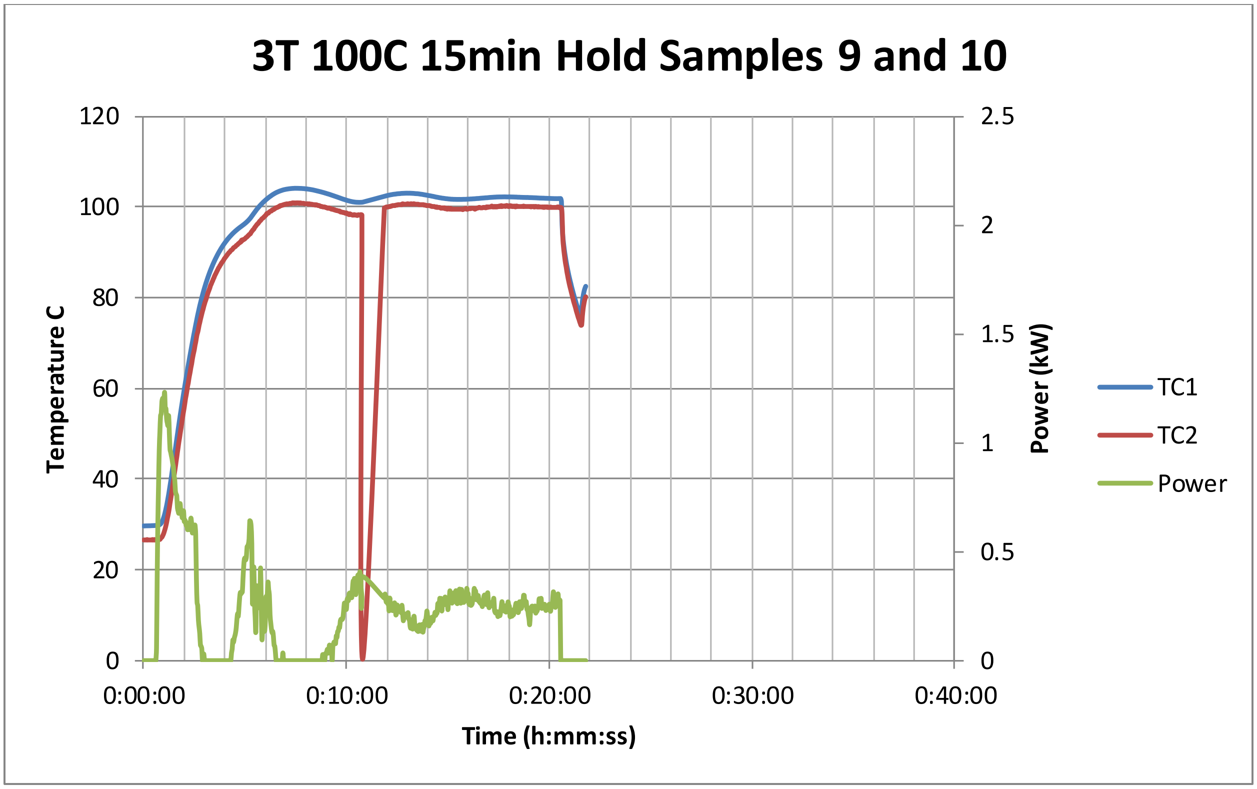

Figure 11 Experimental run data for the 3 T, 100°C/15 min. hold experiments

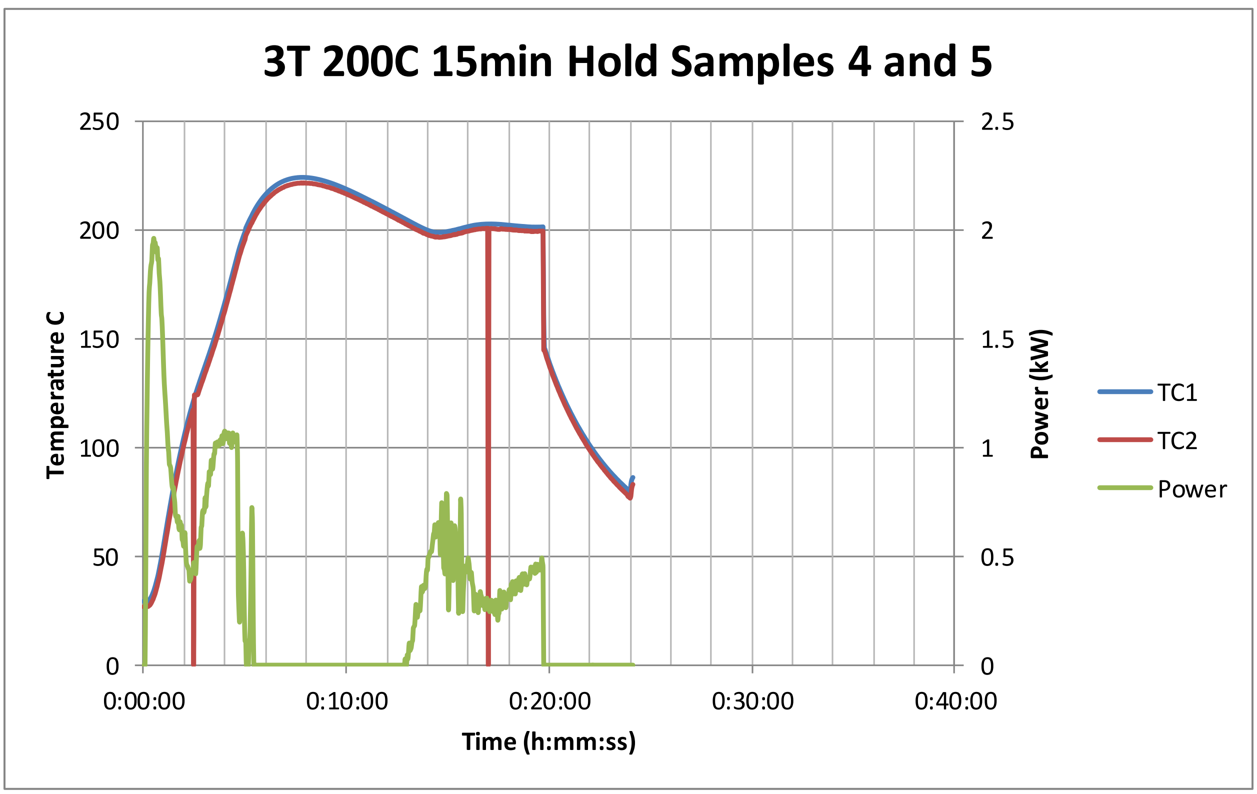

Figure 12 Experimental run data for the 3 T, 200°C/15 min. hold experiments

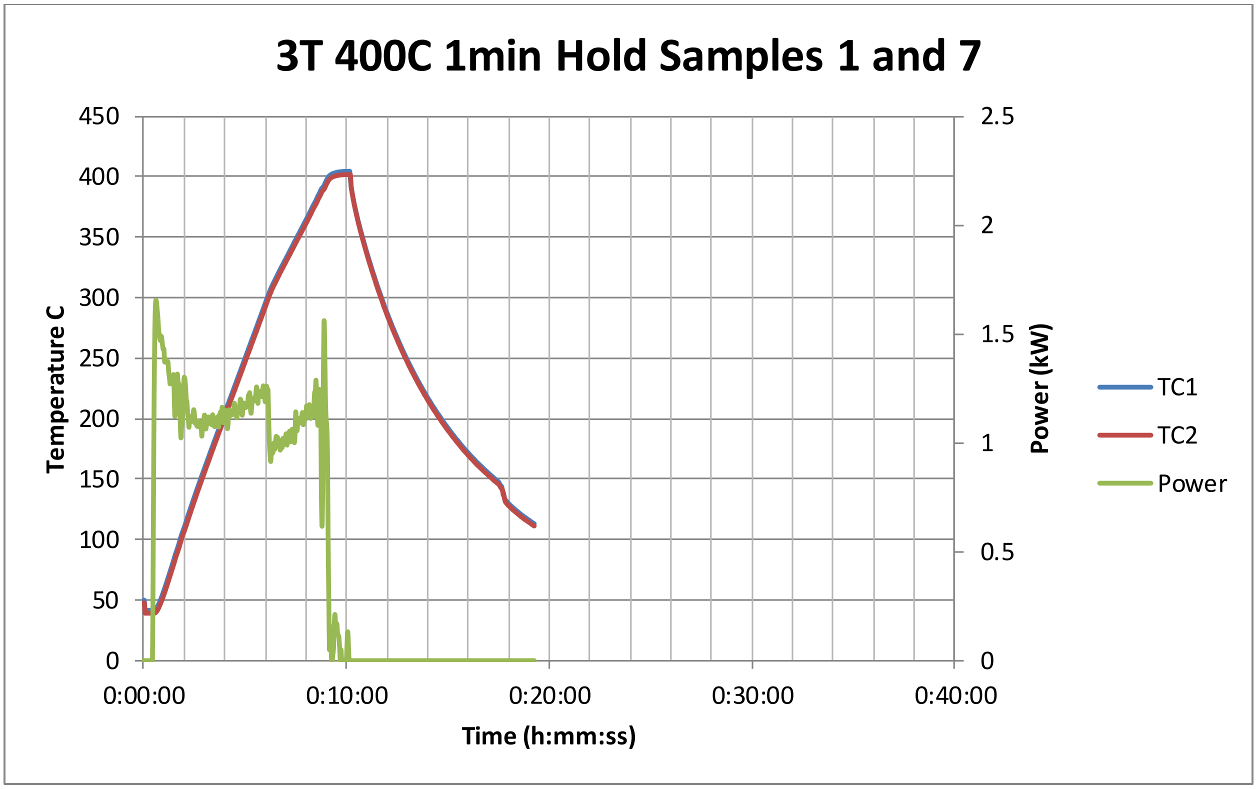

Figure 13 Experimental run data for the 3T, 400°C/1 min. hold experiments

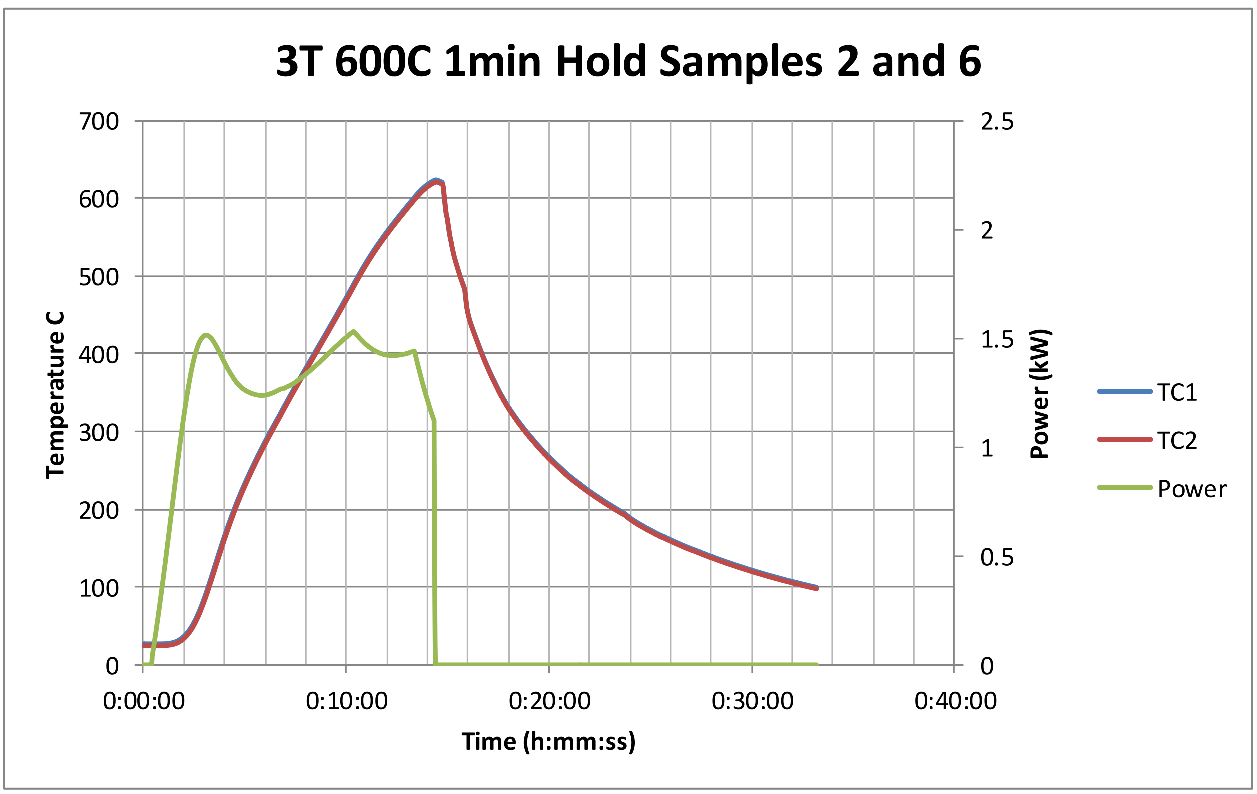

Figure 14 Experimental run data for the 3 T, 600°C/1 min. hold experiments

The second series of HFMP specimens were provided to the industrial partner in 2015. Unfortunately due to changes in priorities and staffing at Metalsa, the location of these samples is unknown and it cannot be determined if any testing was done on the samples. No additional HMFP experiments could be run at ORNL since funding for the project was expended.

Commercialization Potential

Commercial implementation of the HMFP technology is viable today for this truck rail application as very energy efficient superconducting magnet systems can accept a large truck rail when implementing the use of high magnetic fields using induction heating for the tempering operation. The ORNL PI has worked directly with the magnetic designers at American Magnetics Inc. (AMI, Inc.) who proposed the concept drawing below (Figure 15) for a 24-inch diameter bore that could accommodate a custom induction heating coil designed specifically for the truck rail cross section per discussion with AjaxTOCCO Magnethermic induction heating system design engineers. The short time at temperature (5 minutes) that achieved the yield strength and ultimate tensile strength improvements is readily accommodated in a production process by slowly feeding the truck rail into the bore of the magnet-induction heating assembly at the appropriate speed that is definitely amenable to production rate needs.

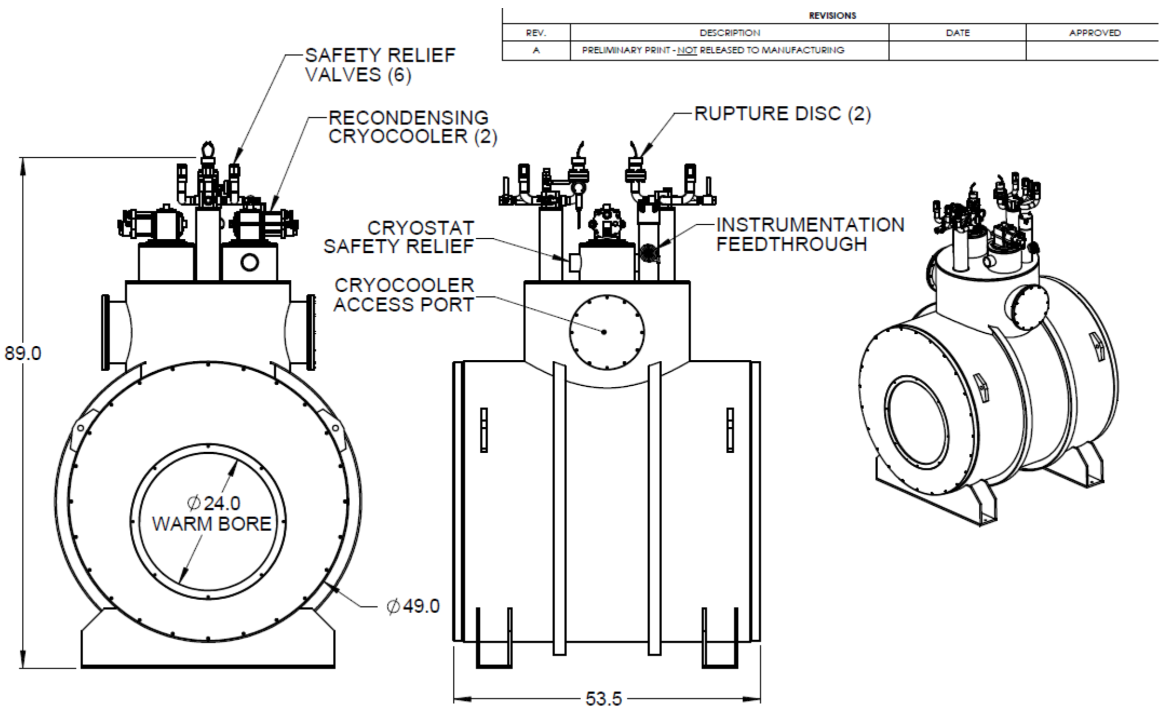

Figure 15 Concept drawing provided by AMI, Inc. for a 1-tesla, recondensing cryocooler-based, 24-inch (610 mm) diameter warm-bore superconducting magnet system.

Impacts

For the truck industry and the broad industrial sector this HMFP technology has demonstrated the evolution of a much more energy efficient and lower-carbon footprint process to be used in the future to produce stronger, tougher, and lighter weight truck rails. The property increases in the truck rails themselves will enable lighter weight truck side-rails to be produced which will reduce the overall weight of heavy duty trucks which will reduce fuel consumption and be an enabler of the goals of the DOE

EERE SuperTruck Program where fuel consumption reductions of 50% are targeted for the future generation of trucks.

Conclusions

The results of this investigation are inconclusive. Although two sets of samples were processed at ORNL, one set of samples was not properly treated before shipping to ORNL and there are no results available from the second set of samples. Previous work by the partners indicated that the thermomagnetic processing technology has potential commercialization applications from process energy efficiency improvement perspectives, as well as making improvements in component properties for the truck rail application.

About the Company

Metalsa is a worldwide enterprise committed in providing best in class innovative structures offering full engineered solutions to best serve its customer's needs.

Metalsa has Technical Centers & engineering locations strategically located near the original equipment manufacturers (OEMs) to fully support product development by experienced technical personnel in manufacturing and new technology development. The extensive range of product development capabilities, allows Metalsa to exceed its customer needs, guarantee engineering requirements and develop competitive advantages through innovation.

Taking into consideration low cost and investment Metalsa's research processes are mainly focused in 3 categories: light weight structures at low cost, safe structures at low cost, and flexible process designs eliminating dedicated equipment and reducing costs.

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