Final Project Summary Report

Project Title: "NDT of Fracture Toughness for Pipeline Steels"

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SBIR Phase I

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Project Summary

The Office of Pipeline Safety, within the Pipeline and Hazardous Materials Safety Administration (PHMSA), is responsible for regulating the products transported by the 2.8M miles of pipelines throughout the country. The industry recommended practices to assess fitness-for-service (API RP 579-1 and API 5L) require knowledge of the fracture toughness of pipeline steels.

Unfortunately, too many pipelines have undocumented properties. Moreover, nondestructive determination of fracture toughness for in-service pipeline steel is challenging. One potential method of nondestructively determining fracture toughness is by means of nonlinear ultrasonic testing. Nonlinear features of ultrasonic wave propagation are sensitive to material nonlinearities associated with microstructure (based on composition, processing, and ageing) that dictate fracture toughness. Prior results indicate that ultrasonic nonlinearity is related to fracture appearance transition temperature, which in turn is related to fracture toughness, as well as other microstructural degradation mechanisms including stress-corrosion cracking, fatigue, and heat treating. The observed correlation between the ultrasonic nonlinearity parameter and fracture toughness is far from surprising. Experimental observations have indicated that ultrasonic nonlinearity parameters of metals are sensitive to the presence of microstructural features such as dislocations, precipitates and microcracks, the same features that promote plastic deformation and brittle fracture. The primary objective of this Phase I project was to develop a method of nonlinear ultrasonic testing for measuring fracture toughness in pipeline steels and demonstrate a correlation between measured material nonlinearity and Charpy impact test results.

Over the course of the Phase I project, Guidedwave fabricated a series of carbon steel specimens having a range of fracture toughness values by heat treating and tempering 4130 alloy steel. Charpy V-notch coupons were cut from these specimens and tested at Penn State University for hardness and Charpy impact energy. Guidedwave then developed a lightweight, small-footprint transducer assembly for

collecting repeatable nonlinear ultrasonic measurements and demonstrated a correlation between Charpy impact energy (KV) and material ultrasonic nonlinearity (ß'). Furthermore, these measurements were conducted with a battery-operated, man-portable pulser/receiver platform amenable to field testing.

The relationship between ultrasonic nonlinearity measured by Guidedwave's system and the material fracture toughness would allow for field characterization of fracture toughness using a simple, handheld transducer and a man-portable hardware platform, with minimal operator interaction or interpretation. However, additional testing and development will be necessary to fully characterize the accuracy and capabilities of the technology and to bring it to a commercially-viable state. To facilitate maturation of the technology demonstrated during Phase I, Guidedwave recommends Phase II objectives to include advancing the nonlinear ultrasonic nondestructive fracture toughness measurement technology to TRL 6 or 7, verifying the results on aged specimens and/or field specimens, performing a more-complete analysis of correlation between ß' and KV, and developing a prototype, field-portable hardware and transducer, a beta version of the nonlinear measurement software, and procedures and algorithms to maximize measurement accuracy, robustness, and repeatability.

Guidedwave personnel have a solid understanding of the technical and economic aspects of commercialization of guided wave ultrasound-based systems. Guidedwave has extensive experience in partnering with larger firms to work toward the commercialization of new technologies. Ultrasonic guided wave technology is relatively new and has only just started to become commercially available within the past 10 years. Guided wave non-destructive testing equipment sales revenue currently makes up less than 1% of the $250 million/year ultrasonic NDT equipment market. There is no doubt this percentage will increase drastically over the next few years as guided wave technology is further developed, and as new products are released to the market. The non-destructive method for evaluating pipeline fracture toughness would be utilized throughout the oil & gas, chemical, and nuclear sectors, and would also find applications in a wider range of industries for which fracture toughness measurements on other steel structures would be highly valuable. Through past projects, Guidedwave has developed a large list of clients and customers. Guidedwave will draw upon these clients and a market survey to seek out additional applications of this technology.