Lifetime Enhancement of Propulsion Shafts Against Corrosion Fatigue by Laser Peening

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The paper's Introduction and Summary are provided here. To read the paper in its entirety, visit the online library at www.shotpeener.com. The document ID number is 2019012.

THIS PAPER REPORTS substantially enhanced fatigue and corrosion-fatigue lifetimes of propulsion shaft materials, 23284A steel and 23284A steel with In625 weld overlay cladding, as a result of shot or laser peening. Glass reinforced plastic (GRP) coatings and Inconel claddings are used to protect shafts against general corrosion and corrosion pitting. However salt water leakage penetrating under a GRP can actually enhance pitting leading to crack initiation and growth. Fatigue coupons, untreated and with shot or laser peening were tested, including with simultaneous salt water immersion. Controlled corrosion of the surfaces was simulated with electric discharge machining (EDM) of deep pits enabling evaluation of fatigue and corrosion-fatigue lifetimes.

Results specifically show high energy laser peening (HELP) to be a superior solution, improving corrosion-fatigue resistance of shaft and cladding metal, reducing the potential for corrosion pits to initiate fatigue cracks and dramatically slowing crack growth rates. At a heavy loading of 110% of yield stress and with 0.020 inch deep pits, laser peening increased fatigue life of the steel by 1370% and by 350% in the corrosion-fatigue testing.

INTRODUCTION

Prevention of corrosion-induced fatigue cracking of propulsion shafting is an important operational and safety requirement and thereby significantly impacts the construction and operational cost of ships. The issue is specifically important for submarines where viability of shafts specifically defines operation limits.

In ship operation, shafts undergo heavy mechanical loading while simultaneously exposed to the salt water environment. Shafts are often fabricated using weld-overlay Inconel coatings and glass reinforced plastic (GRP) coatings to protect against corrosion and corrosion pitting. However salt water can seep under the coatings where the confined environment actually exacerbates corrosion pitting (crevice corrosion) leading to early fatigue crack initiation. Consequently ship inspection and overhaul schedules are often dictated in time to ensure shaft integrity. The issue is of particular importance to submarine safety.

As summarized by Jonart in his thesis, "Submarine propulsion shafts have demonstrated acceptable reliability performance when inspected and refurbished at least every six years (Jonart 2014). Designers wish to extend the inspection interval to 12 years without sacrificing reliability. This interval is unprecedented, as no known submarine shafting system is currently operated with this inspection cycle, nor are any known commercial vessel shafts. Experience and improved design have eliminated many threats to the life of

The prevention of corrosion-induced fatigue cracking is especially important for submarines where the viability of propulsion shafts affects operation limits.

Photo: The Ohio-class ballistic missile submarine USS Nebraska in Puget Sound, Washington. The Nebraska recently completed a 41-month engineered refueling overhaul. The overhaul will extend the life of the submarine for another 20 years. This U.S. Navy photo was taken by Mass Communication Specialist 1st Class Amanda R. Gray.

a submarine shaft, but inspections of existing shafts show a high percentage with signs of wetting, leaving designers with less-than-acceptable confidence to approve this longer inspection interval due to the possibility of corrosion-fatigue failure." Jonart's uses probabilistic models from literature for pitting and cracking of wetted shafts along with Monte Carlo simulations to predict expected times from shaft wetting to pitting, to crack initiation and growth and to eventual shaft failure. Based on allowable risk, this type of modeling is used to set allowable time intervals between shaft inspections. Reducing the potential for shaft failure would greatly enhance safety and could increase inspection intervals and thereby enable significant cost savings and increased ship availability.

In this work we evaluate fatigue lifetimes of 23284A steel, a steel used for propulsion shafts, alone and in the presence of simultaneous salt water exposure (corrosion-fatigue lifetimes). We also evaluate the fatigue and corrosion fatigue lifetimes of this steel when deployed with an Inconel 625 weld overlay—an overlay used to inhibit corrosion and corrosion pitting. The work focuses on the ability of shot and laser peening to extend the lifetimes with the intent to enhance safety and reduce shaft inspection and replacement intervals.

SUMMARY

Using fatigue and corrosion fatigue testing, we have investigated the potential of laser and shot peening to extend the lifetime of propulsion shaft material, including 23284A steel and steel with In625 weld overlay. In all cases the tests showed that laser peening significantly increases the lifetime of the shaft material and the weld-overlayed material beyond that of untreated or shot peened material. For 23284A material clad with In625, material less prone to corrosion induced pitting, the laser peening increased the lifetime of a notched sample by over 1300% without a failure occurring.

For the bare 23284A steel, test results are summarized in Figure 17. Propulsion shaft material experiences a 480% loss of fatigue lifetime at 125% of yield stress, following the EDM of a 1 mm diameter by 0.5 micron pit intended to simulate a salt water induced corrosion pit. In contrast, laser peening doubles the lifetime of pitted material at this high stress level. Pitting combined with salt water exposure dropped the fatigue performance by more than five (5) times. Laser peening overcomes much of this deficit, improving corrosion-fatigue by 350%.

Inspection intervals, driven by concern for corrosion-fatigue failure, are a major driver in ship overhaul and hence a driver of cost and ship availability. Laser peening could safely extend inspection intervals.

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