LAMBDA Technologies Group

Diffraction Notes

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Issue No. 47 Improving Component Life and Performance 2019

IMPROVING THE FATIGUE LIFE OF DUCTILE CAST IRON VIA SURFACE ENHANCEMENT

INTRODUCTION

Ductile cast iron is used in a variety of applications from statically loaded structural supports to various dynamically loaded components. It can be an effective and preferred substitute for carbon and low alloy steels, as well as medium alloy steels in some situations, due to lower cost and superior ability to be cast and machined. Surface enhancement treatments such as shot peening (SP) have been used to increase performance of many alloys, including ductile cast iron, by imparting a layer of beneficial compressive residual stress. An optimized surface enhancement process like Low Plasticity Burnishing (LPB®), which imparts deeper, more stable compression than can be achieved with SP, could further improve material performance and broaden the range of applications in which ductile cast iron can be used.

Lambda Research conducted a residual stress and high cycle fatigue (HCF) life investigation on the effectiveness of various surface treatments on ASTM A-536 80-55-06 ductile cast iron. Fatigue performance was evaluated for ground (baseline), SP, and LPB processed samples. The effect of damage mechanisms such as notched surface defects and active corrosion fatigue (CF) was also studied.

MATERIAL PROCESSING

HCF test samples were machined from bar stock and low stress ground prior to any surface treatment. SP was performed to an Almen intensity of 9A and a coverage of 150% with CCW14 steel shot. LPB processing was performed at Surface Enhancement Technologies (SET) using conventional CNC vertical milling centers and proprietary LPB processing parameters.

Some sample sets were tested with a 0.020 in. deep notch to simulate mechanical damage or corrosion pitting. Notches were introduced using electrical discharge machining (EDM) which provides a highly reproducible flaw with residual tension and cracks in the recast layer at the bottom of the notch.

Several sets of HCF tests were performed in CF using a 3.5% NaCl solution. CF was achieved by attaching a pad, saturated in the salt solution, to the gage region. The saturated pad was sealed in order to keep the gage region moist during the duration of the test.

HIGH CYCLE FATIGUE

HCF tests were performed under constant amplitude 4-point bend loading at Lambda's Surface Integrity & Process Optimization (SIPO) laboratory. Results are presented graphically as a stress vs. life (S-N) plot in Figure 1 and as percentage of baseline fatigue limit (at 10 million cycles) in Figure 2. Figure 3 is a bar plot of HCF and CF life for each surface process tested with simulated damage at 50 ksi.

It was shown that, in the absence of damage, the fatigue limit of ground ductile iron is improved by about 25% with the application of LPB processing. When subjected to 0.020 in. deep surface damage, the LPB sample group had nominally twice the fatigue limit of the baseline and SP sample groups. LPB processing effectively restored the fatigue limit of samples damaged to 0.020 in. to within 80% of the undamaged baseline value. All LPB processed samples tested in CF with 0.020 in. deep notches at 50 ksi ran out to 10 million cycles, exhibiting greater than 10 times the fatigue life of both the baseline and SP samples.

RESIDUAL STRESS

X-ray diffraction residual stress distributions measured at Lambda's test facility are shown as a function of depth in Figure 4. Depth of compression was approximately 0.002, 0.010, and 0.030 in. for the baseline, SP, and LPB conditions, respectively. Residual stress results support the fatigue findings. Compression that extends deeper than the damage provides a benefit. Deeper compression afforded by LPB is able to reach below both the corrosion damage and simulated 0.020 in. damage to provide the highest fatigue benefit.

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SUMMARY

- LPB and SP improved baseline fatigue performance by at least 25%.
- 0.020 in. damage caused a 65% debit in baseline fatigue life and 60% debit in SP condition. LPB condition showed a debit of only 20%. LPB restored fatigue life to 80% of the baseline undamaged condition.
- When subjected to 50 ksi CF in combination with a surface notch, LPB extended the fatigue life by more than a factor of 10 over baseline and SP conditions.
- Baseline and SP compression was less than 0.010 in. deep. Damage on that order or deeper produced a significant fatigue debit reducing the fatigue strength to less than 50% of the baseline. LPB compression provides protection from deeper damage and corrosion attack.

In summary, not only did LPB provide a significant improvement in fatigue life, it effectively improved damage tolerance and mitigated corrosion effects during cyclic loading, restoring the fatigue limit typically lost in CF. Optimizing the introduction of deep compression into ductile cast iron components via surface treatments such as LPB can greatly improve damage tolerance and fatigue performance in corrosive and non-corrosive environments.

Please see our website at www.lambdatechs.com for the full technical paper and complete list of references.

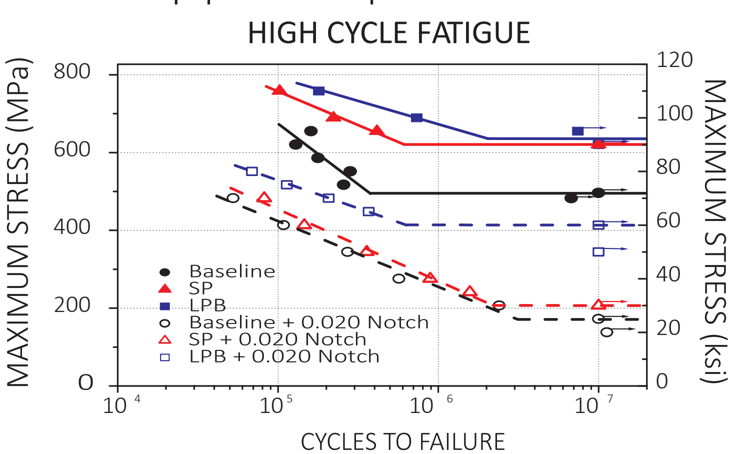

Figure 1: HCF Results of Samples Tested with a 0.020 in Notch

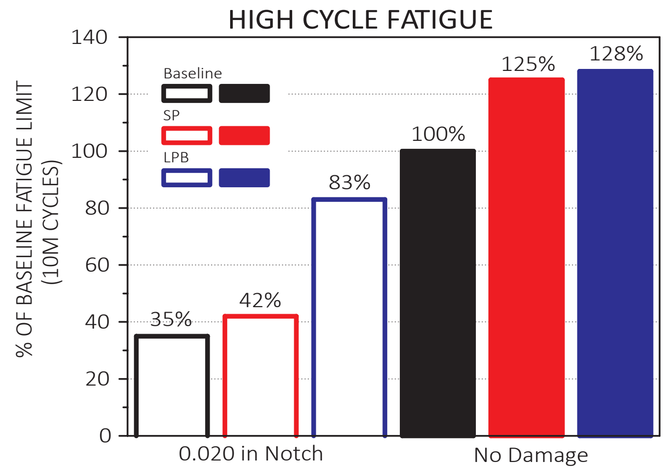

Figure 2: HCF Results Plotted as a Percentage of the Baseline Fatigue Limit

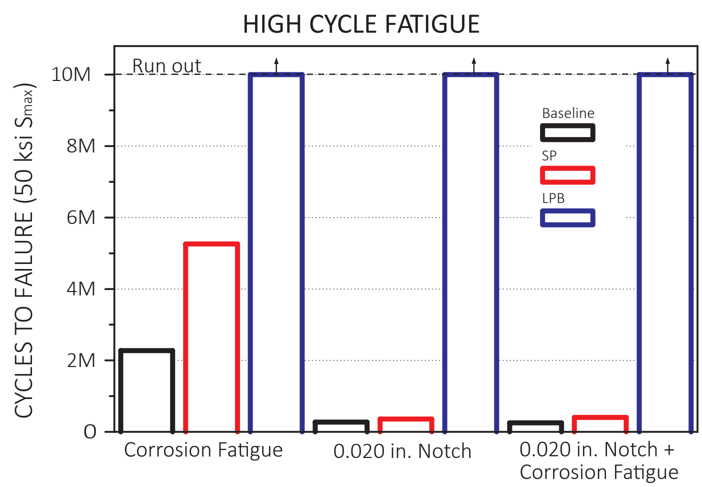

Figure 3: HCF Results at Smax = 50 ksi

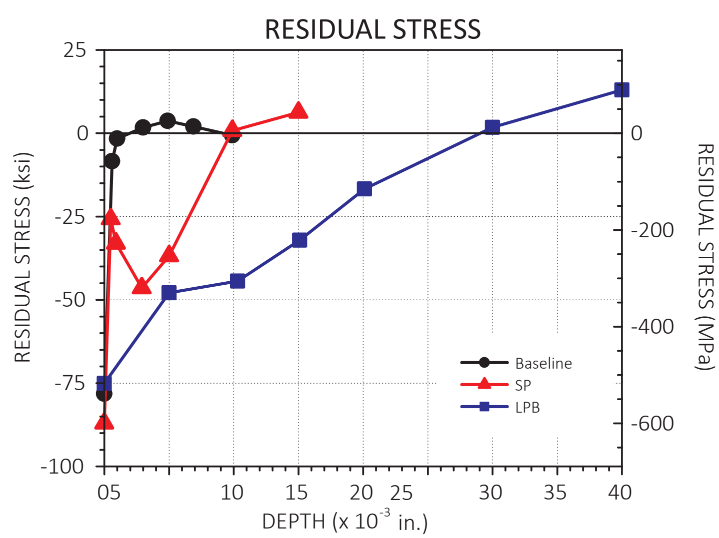

Figure 4: Residual Stress Distributions of Processed Test Samples

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