Comparing the low-frequency performance of maraging and glassy metal cantilever blade springs

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Introduction

Virtually all cantilever blade springs used in gravitational wave detectors for seismic attenuation are made with maraging steel. Geometric anti-spring filters made from this material and designed to reach arbitrarily low resonant frequencies have shown instabilities that impede their tuning below ½ Hertz.

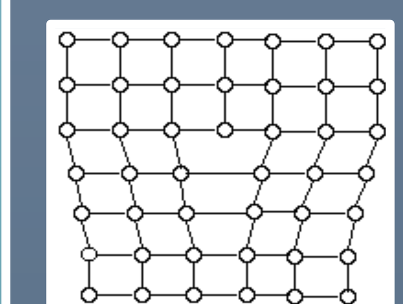
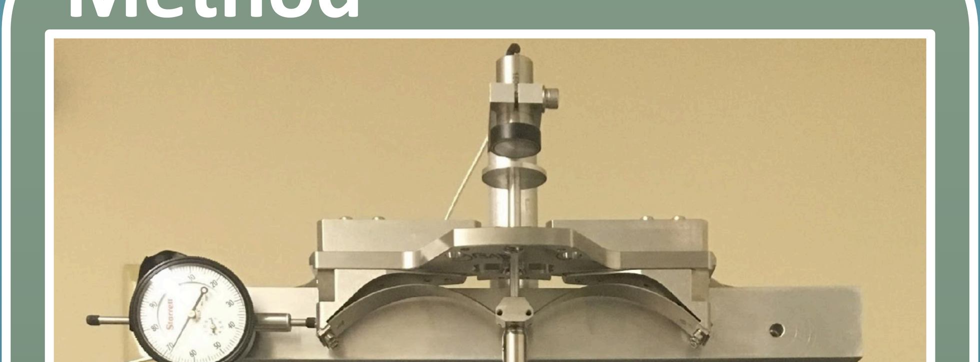


Fig 1: Dislocation in a crystal.

The instability and low frequency noise can be attributed to self-organized criticality effects within the material. The suspects are avalanches of disentangling/re-entangling dislocations that randomly change the filter's equilibrium point.

Method



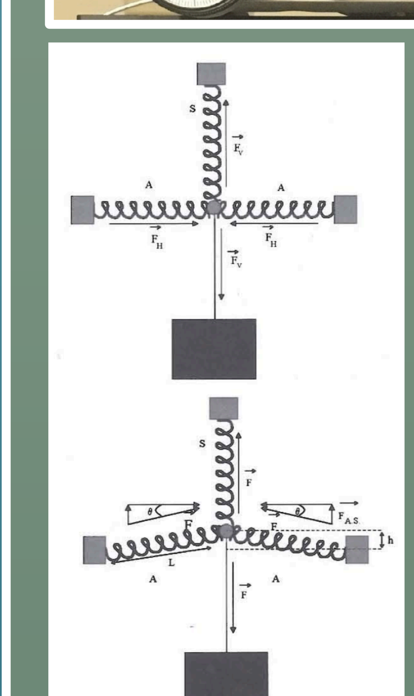


Fig 2: Blade tuning fixture and free body diagram (left). Increasing radial compression results in stronger antispring and lower resonant frequency.

Maraging steel blades were tested along side the vitrelloy 105 glassy metal blades in the design shown in Figure 2. Glassy metals are free of dislocations and thus a hopeful candidate for removing the instability below 0.5 Hz.

Results

The goal was to test glassy metal blades to determine if they remove the low instability noise in the GAS filter set-up.

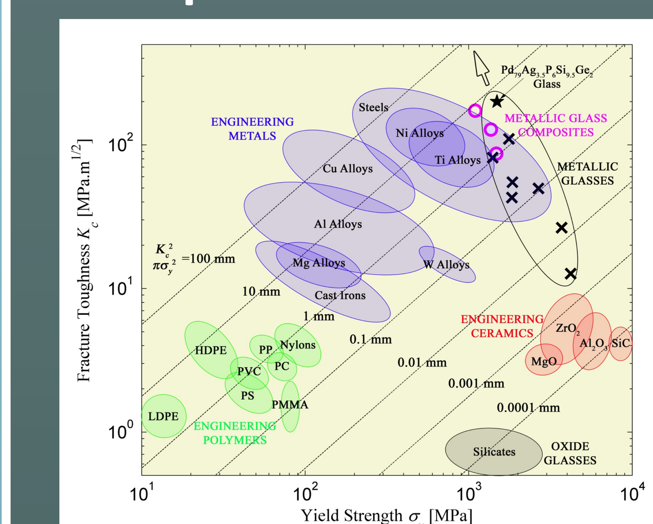


Fig 3: Plot of Toughness vs. Strength trade-off.

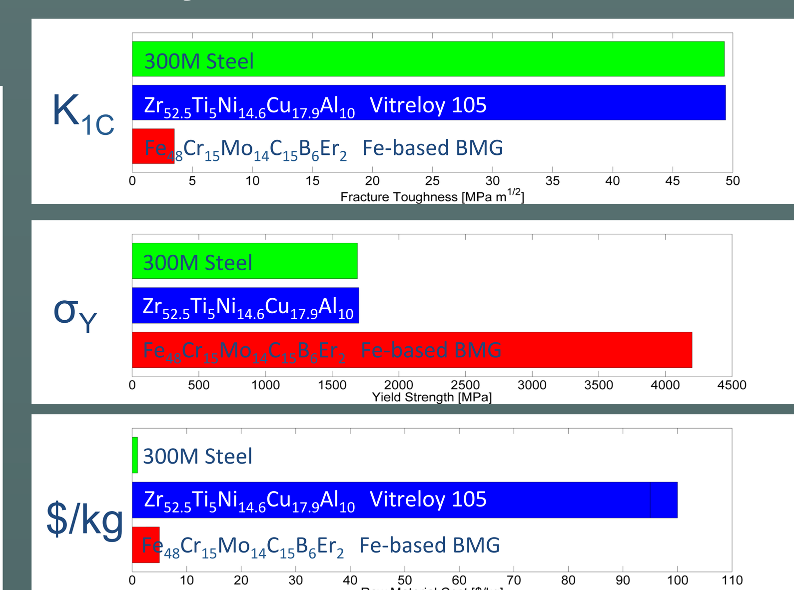


Fig 4: Metrics for 300M Steel (similar to maraging), Vitreloy 105 (LM105).

The LM105 material proved more brittle than previously tested glassy materials (a GAS spring built years ago is still operational). The expected fracture toughness is shown in Figures 3 and 4. Since the two samples of different thickness shattered, a comparison with maraging was not possible. A limited set of data was obtained with the second, thinner set of blades. Q-Factor results for the set of maraging steel blades appear in Figure 5 alongside preliminary results from the LM105 glassy metal blades.

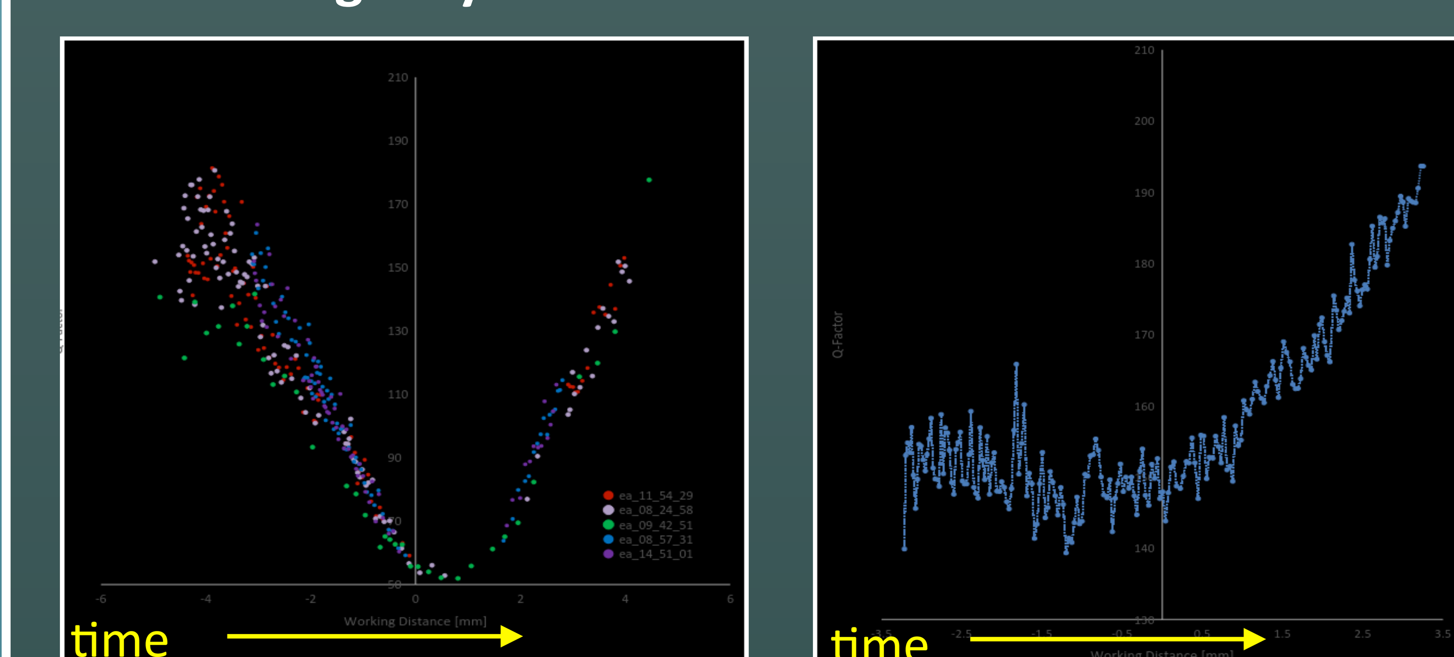


Fig 5: Plot of the Q-Factor of the maraging steel blade (left) and the LM105 blades (right) versus their corresponding resonant frequencies.

$$Q = \pi f \tau$$

This data was taken when the blades were tuned to the largest radial compression allowed by the apparatus, which limited the lowest possible resonant frequency to a frequency of 1.4 Hz. Spacers were machined to allow for more compression, however the blades shattered when dismounting. During the break the blades gave off a flash of visible light due to surface oxydation ignited by the sudden transient of stress concentration.

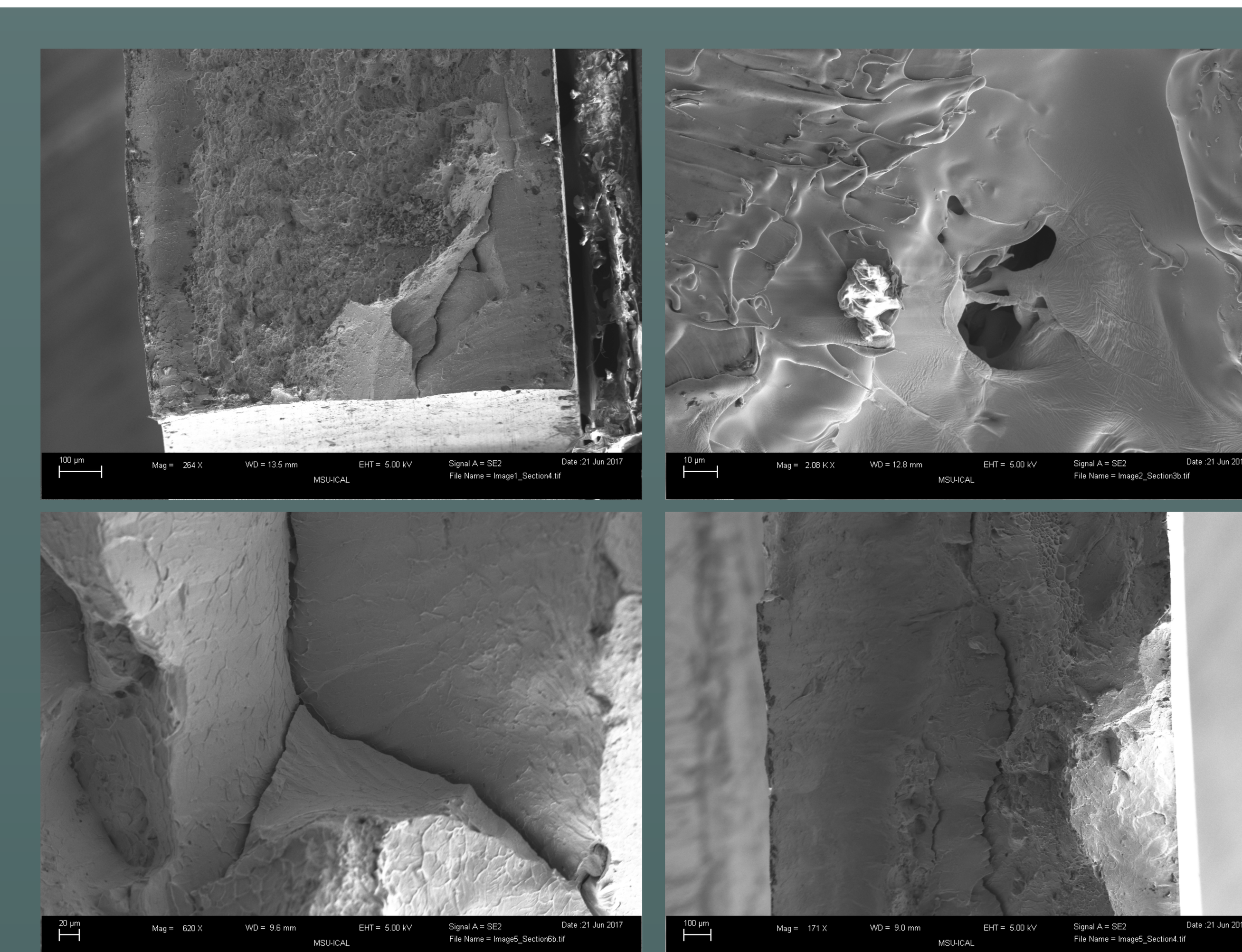


Fig 6: SEM images of the fractured surfaces of the LM105 blades.

There are two possibilities as to why the blades shattered. First, the LM105 purchased was not good quality (the fracture toughness was much less than predicted).

$$R_{\text{critical}} = \frac{{K_{1C}}^2}{\pi {\sigma_y}^2}$$

Secondly, impurities (i.e. crystals, cracks, pockets of gas) formed during the casting process were larger than R_{critical} (the smallest a defect can be before causing catastrophic failure) and caused the material to shatter before reaching its yield point.

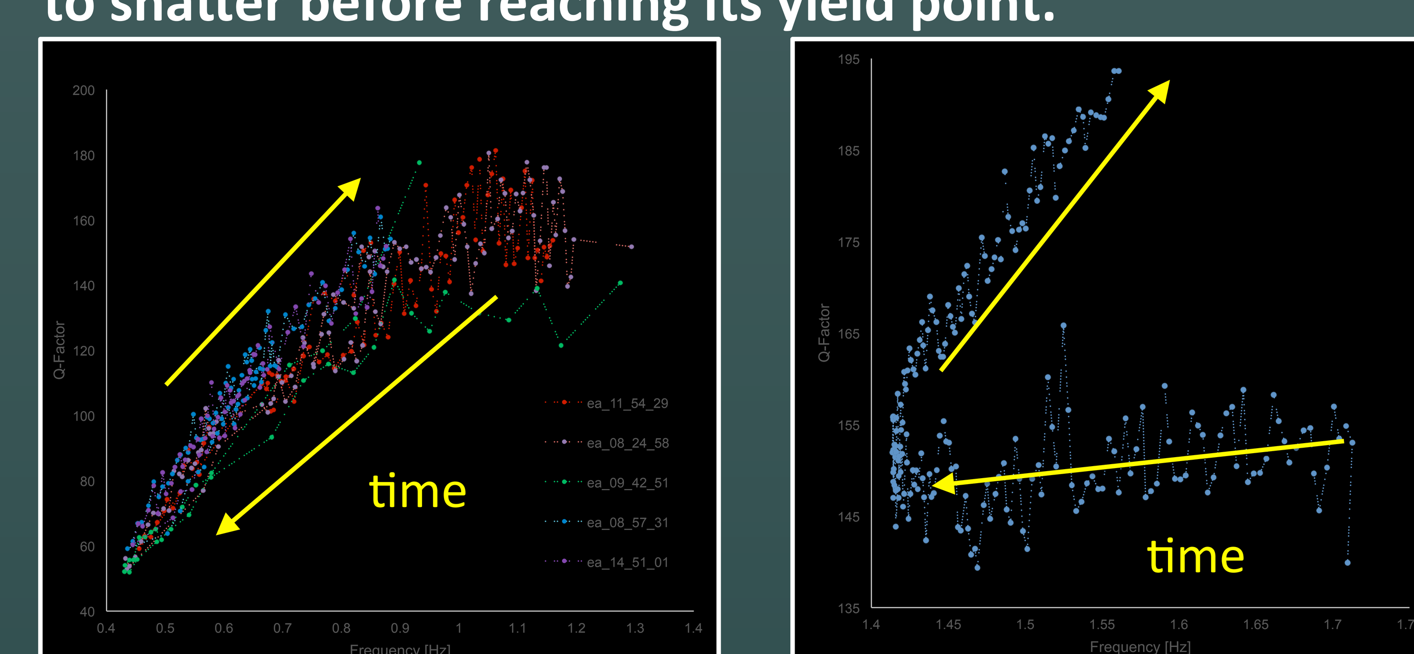


Fig 7: Q-Factor vs. resonant frequency for the maraging steel (left) and LM105 (right) blade sets. Note the yellow arrows indicate time.

Although preliminary, interesting behavior was observed in the Q-Factor at the same frequency as the spring moves through the working point with increasing mass steps. This was seen in both the glassy metal and the maraging steel samples.

Conclusions

Despite the results from this study we are still hopeful that a glassy material will prove to be a replacement for maraging that will allow GAS springs to be tuned down in frequency without exhibiting the same instabilities. An almost 10 year old GAS spring is still operational and an investigation is going on in collaboration with the LM105 vendor to understand why it is more brittle than specified. If a suitable glassy metal can be found and low frequency operation achieved, it would validate the dislocation avalanche theory and allow for lower frequency mechanical attenuators for detecting gravitational waves from more massive black holes.

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