WHITE PAPER

FATIGUE RESISTANCE OF STRUCTURAL ADHESIVES

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Abstract

Adhesive selection in high dynamic load environments relies heavily on mechanical adhesive properties, including shear, peel and compressive strength. Over time and in the life a part, fatigue can occur to metals, plastics and adhesives. Fatigue weakens the overall strength of these components and can lead to premature failure. In the case of adhesives, shear strength values may depreciate an order of magnitude, from thousands to hundreds of psi due to a life of wear and dynamic movement, which can lead to failure. When selecting an adhesive for bonding a joint, the likely first choice is the adhesive with the highest shear strength with the assumption that the higher the shear strength the longer the part will last. However, upon testing, higher shear strength does not directly correlate to a longer part life.

In the case of hybrid adhesives (Loctite® HY4090GY™ and HY4070™) compared to epoxies (Loctite® E-20HP™), the epoxy greatly outperformed the hybrids in shear strength, but the hybrids greatly outperformed the epoxy in limit of endurance. Overall, the methyl methacrylate (MMA) adhesive (Loctite® H8003™) proved to be the most fatigue resistant adhesive tested.

Introduction

Across the adhesives industry there are adhesives that are referenced as structural and non-structural bonders. Structural bonders are perceived as strong durable adhesives bonding two pieces together while non-structural bonders are typically weaker adhesives that are exposed beads of cured adhesive, as in potting. Examples of each would be using an epoxy to bond two pieces of steel together (structural) and using a silicone or silane modified polymer (SMP) to seal the seam between a bathroom tub and floor to prevent water getting into the basement (non-structural). It should be noted however, there are several applications where a non-structural adhesive can be used as a structural adhesive, such as gasketing or windshield bonding.

Two-part epoxy adhesives are well known as very strong metal bonders with great resistance to environmental conditions as well as chemical conditions. Two-part acrylic adhesives are well known for their ability to bond plastics, resist vibration and impact. Henkel then combined both technologies with cyanoacrylate chemistry to develop universal structural bonders known as hybrids. These were formulated to bond to several different substrate materials, including both metal and plastic, as well as provide fast fixture speed while maintaining the durability of an epoxy and toughness of an acrylic. The goal of this paper is to evaluate the epoxy, acrylic and hybrid chemistry for fatigue resistance.

Definitions

SMP – Silane Modified Polymer
GBMS – Grit-Blasted Mild Steel
MMA – Methyl Methacrylate
Limit of endurance – The highest stress that a material can withstand for an infinite number of cycles without breaking (Merriam-Webster)

Analysis

Methods:

The shear strength was determined using a Henkel Lapshear Strength Method, referencing ASTM D1002-05, Strength Properties of Adhesives in Shear by Tension Loading (Metal-to-Metal). For the shear strength testing, grit blasted mild steel (GBMS) lap shears were bonded with a 0.5” overlap and an induced 0.011” gap with glass beads. For Loctite® H8003™, which has built in 0.011” spacers, an additional gap was not induced. A minimum 7-day standard laboratory conditions cure was used. The testing was conducted at a crosshead speed of 0.08 inches per minute.

The shear strength results were then evaluated for a 95% confidence interval to determine the loads at which to be used for fatigue testing. The bottom level of the 95% confidence interval was deemed as the proof load (1 cycle) and used to determine the loads necessary to generate an S-N curve. An S-N curve is a stress vs cycles plot to determine finite and infinite life of an assembly. The percent proof loads tested were 20%, 40%, 60% and 80%, with a few exceptions. A limit of 36 million cycles was set for the test. ASTM-D3166 was referenced for testing. Specimens were cyclically fatigued (Figure 1) from the target proof load of 20%, 40%, 60% and 80% (σmax) to 10% of the target proof load (σmin). The specimens were bonded identically to the shear strength specimens, except a 0.4” overlap was used.

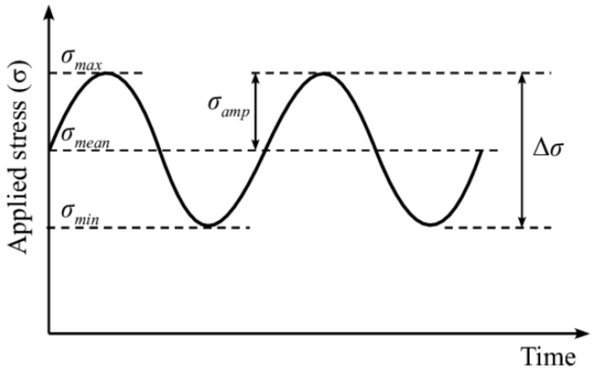

Figure 1: Cyclic loading of fatigue testing (Bastidas-Artega)

Materials:
GBMS Lapshears – (1”x4”x0.063”)
Results and Discussion

Graphs:
The graph below (Figure 2) shows the S-N curves of the tested products, which are best fit logarithmic curves on a linear scale. It is observed that the best fatigue resistant adhesive was Loctite® H8003™ and the least fatigue resistant adhesive was Loctite® E-05CL™.

Figure 3 is a compact version of Figure 2, zoomed in to show the trendline interactions below 3 million cycles. It is observed that the fatigue resistance of Loctite® E-20HP™ falls below the fatigue resistance of Loctite® HY4080GY™, HY4070™ and HY4090GY™ prior to 500,000 cycles.

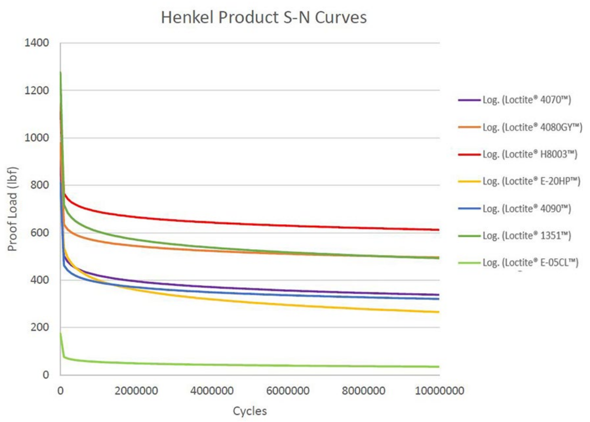

Figure 2: S-N Curves of Henkel Products

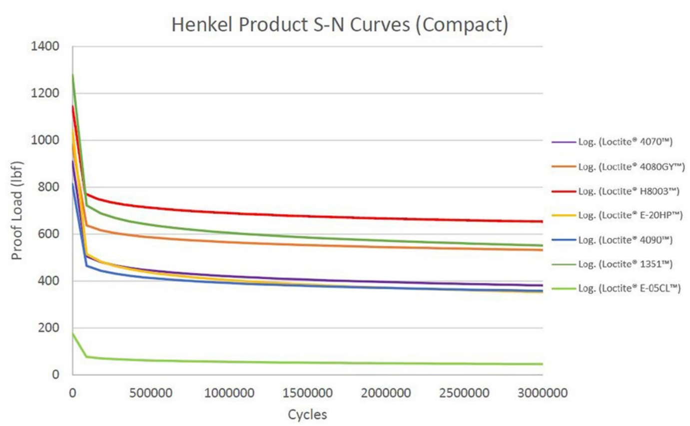

Figure 3: S-N Curves of Henkel Products Below 3 Million Cycles

The chart below (Figure 4) shows the ultimate strength determined by shear strength testing, the limit of endurance and the % strength retention at the limit of endurance.

Limits of Endurance – τ_D ($2x10^7$ cycles, R0.1)				
Adhesive	Ultimate Strength (psi)	Limit of Endurance (psi)	Limit of Endurance (MPa)	% Limit of Endurance/ Ultimate Strength
Loctite® H8003™	3064	1475	10.2	48.1
Loctite® 4080GY™	2950	1187	8.18	40.2
Loctite® 1351™	2560	1147	7.91	44.8
Loctite® 4070™	2496	784	5.41	31.4
Loctite® 4090GY™	2276	750	5.17	33.0
Loctite® E-20HP™	3032	660	4.55	21.8
Loctite® E-05CL™	998	72	0.5	7.2

Figure 4: Limits of Endurance

Conclusions

Overall, the highest limit of endurance was Loctite® H8003™ (MMA), which coincides with acrylics exhibiting high shear, impact and good elongation. The lowest performer was Loctite® E-05CL™, a 5-minute epoxy that is typically used for potting.

Hybrid adhesives lacked initial bond strength comparatively, but overall, performed better than the high performance epoxy, which is typically considered to be very durable. The rigid polyurethane adhesive, Loctite® 1351™, showed high fatigue resistance, but when there was >50% of the proof load, nearly all strength was lost within a small percentage of the cycles.

Based on the data, we see that the MMA retained about 48% of its initial ultimate strength, Hybrids retained between 35% and 40%, the polyurethane retained about 45% ultimate strength and epoxies retained 7%.

In general, MMA’s should be considered for reasons of impact strength, shear strength and long-term fatigue resistance in metal to metal bonding. Due to the substrate versatility of the hybrid adhesives, hybrids should be considered for use in metal to plastic bonding for high shear strengths and good fatigue resistance. Polyurethanes can show good bond strength on metals and epoxy-based materials and should be considered for those applications for high shear and fatigue resistance. Epoxies should be considered for applications in metal to metal bonding that are relatively static due to weak fatigue resistance exhibited.

References

ASTM D1002-05(2005), Standard Test Method for Strength Properties of Adhesives in Shear by Tension Loading (Metal-to-Metal), ASTM International, West Conshohocken, PA, 2005, www.astm.org

ASTM D3166-99 (2012), Standard Test Method for Fatigue Properties of Adhesives in Shear by Tension Loading (Metal/Metal), ASTM International, West Conshohocken, PA, 2012, www.astm.org

Bastidas-Arteaga, Emilio. *ResearchGate*, Sept. 2009, www.researchgate.net/figure/Fatigue-loading-a-Simple-constant-amplitude-cyclic-stress-fluctuation-b_fig7_278645971.

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Acknowledgements

Robert Chen – for his contributions to the bonding and testing of the cured lap shears in both shear and fatigue.

Appendix

Fatigue Test Parameters					
Adhesive	**Proof Load (psi)**	**80% (psi)**	**60% (psi)**	**40% (psi)**	**20% (psi)**
4070	2170	1736	1302	868	434
4080	2412	1930	1447	965	482
4090	1942	1554	1165	777	388
E-20HP	2532	2026	1519	1013	506
E-05CL	454	363	272	182	91
H8003	2798	2238	1679	1119	560
1351	2560	2048	1536	1024	512

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