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# TMG News

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## Failure Analysis of a Medicine Ball

*William Aquite, Ph.D.*

Medicine balls are commonly used in training and for rehabilitation. Their weight, size and ability to bounce vary across the market and suit multiple needs. For instance, while the addition of weight is beneficial for strength training, bouncing balls allow for more athletically-based workouts. This article studies the failure of a weighted medicine ball that cracked during use in an exercise drill that included repeated bouncing. This evaluation identified features that were characteristic of failure occurring through low cycle fatigue associated with the bouncing of the product during use. Cracking of the medicine ball may have resulted due to a combination of low air pressure and uneven thickness distribution throughout the elastomeric materials in the shell of the product.

**What Went Wrong?**

The Madison Group (TMG) analyzes hundreds of product failures every year. In-situ experiments are often conducted to evaluate the contribution towards failure from material selection, manufacturing, design, intended use and installation practices. However, the failure described in this study, occurred outside of the TMG laboratory facility. Inadvertently, an uncontrolled fatigue experiment took place in the employee fitness room where a medicine ball was used for a slam exercise. In this exercise drill, a medicine ball is thrown down towards the ground. A slam exercise is meant to increase core and functional strength. The amount of force and frequency used for a slam exercise would vary depending on the user's physicality. The medicine ball in this analysis was a weighted ball and would bounce when making contact with the ground when used for this exercise.

Failure was observed after a repetitive slam exercise. Failure affected the structural integrity of the medicine ball and reduced its ability to bounce. The failure event of the ball did not result in any injuries or property damage. However, it prompted questions about the construction and failure of this piece of fitness equipment.

References about the product indicated that the medicine ball's construction allowed it to bounce off of hard surfaces. The ball included an air valve. This indicated that the air pressure inside of the ball aided towards the balls' *bouncebackability* following impact. It should be noted that the air pressure and frequency of use for the failed ball were not monitored throughout its lifetime. It is unknown whether the ball would bounce or not when deflated.

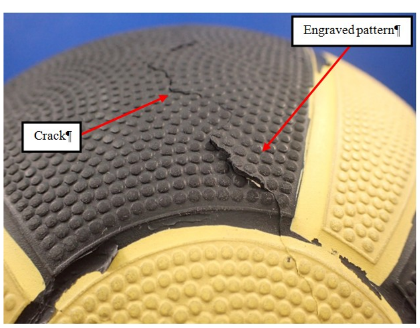


**Figure 1**-View of the continuous crack on the exterior of the medicine ball.

**Failure Evaluation**

A single, continuous crack was observed on the exterior of the medicine ball. The crack appeared to extend through almost half of the circumference of the ball and followed a continuous, but irregular pattern with no visible bifurcations (**Figure 1**). The external surface of the ball featured an engraved pattern. However, the crack propagation did not appear to be

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affected by the external, engraved features nor by any other feature on the exterior, such as color or location relative to the ball's air valve. To further study the crack development, destructive analysis was conducted. This analysis included sectioning of the ball, microscopy and material testing.

No evidence was found to indicate that damage, such as abrasion, gouging or cutting contributed to the failure of the medicine ball. The ball's ability to bounce was notably reduced after the failure and attempts to pump the ball up, showed it was deflated. In order to evaluate the medicine ball's construction and to further study its failure mode, the medicine ball was cross-sectioned.

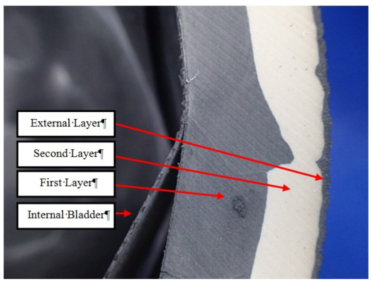



**Figure 2** – View of the internal construction of the medicine ball.

Sectioning of the medicine ball was performed at a location near the observed crack to allow for further examination and exposure of the fracture surface. The sectioning of the ball revealed an internal bladder and a shell composed of three layers of material; (First Layer, Second Layer and External Layer) (**Figure 2**). No sudden or loud noise was reported at the time of the cracking. This could indicate that the air pressure inside of the ball was low or that the ball was already deflated at the time of failure. The bladder showed a rupture in the region adjacent to the main crack location (**Figure 3**). Therefore, it is possible that the rupture of the internal bladder was a post-failure event due to the effects on the structural integrity of the ball from the shell's failure.

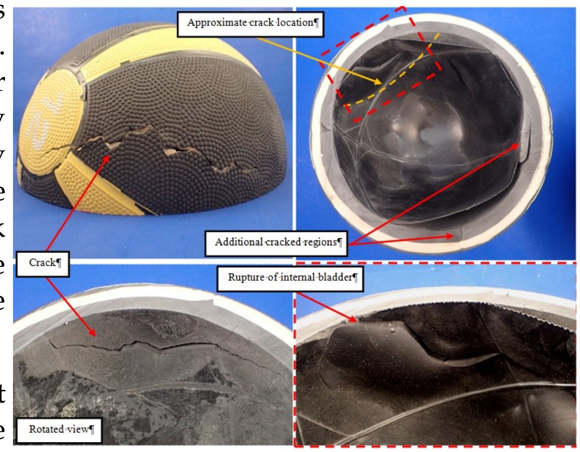



**Figure 3-**Views of the cross-sectioned medicine ball showing the crack location, the ruptured internal bladder and additional cracked regions observed on the First Layer of material.

Thickness measurements on the cross-section showed that cracking occurred at a region with reduced thickness along the circumference of the medicine ball (***Table 1***). The nature and causes of the thickness variation were associated with the manufacturing defects of the medicine ball. The presence of thickness variations can reduce the overall strength of the product, and could have made this region prone to crack development and failure.

| Location | Thickness measurement |
|---|---|
| 1 | 0.736″ |
| 2 | 0.781″ |
| 3 | 0.982″ |
| 4 | 0.878″ |
| 5 | 0.785″ |
| 6 | 0.798″ |
| 7 | 0.866″ |
| 8 | 0.731″ |

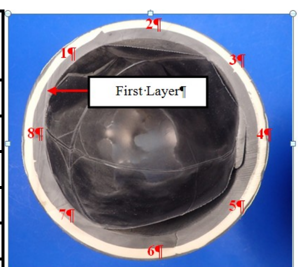



***Table 1*** – Thickness measurements on the cross-sectioned medicine ball. Locations 1, 2 and 8 are coincident with the region where the main crack was observed. Thickness measurements did not consider thickness of the internal bladder.

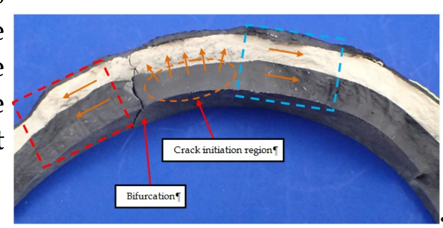
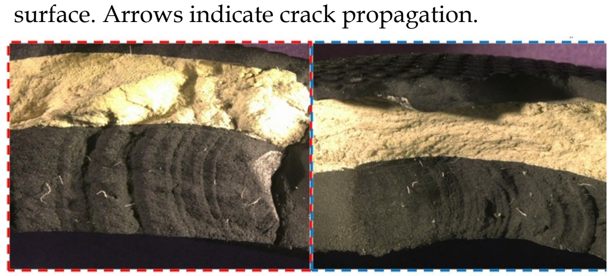



**Figure 4** – Micrograph views of the exposed fracture surface. Arrows indicate crack propagation.



The region of failure showed no visual signs of material defect, degradation or aging. Microscopic examination of the crack surface showed a single crack origin location on the interior of the First Layer of material. The crack initially propagated radially through the shell. Subsequently, the crack extended circumferentially in both directions (**Figure 4**). This pattern of

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crack progression was also observed through the Second Layer and External Layer of material. The observed fracture features were consistent with a progressive failure mechanism, as indicated by the presence of parallel indications. The form and relatively lower number of observed indications were thought to represent crack propagation through low cycle fatigue.

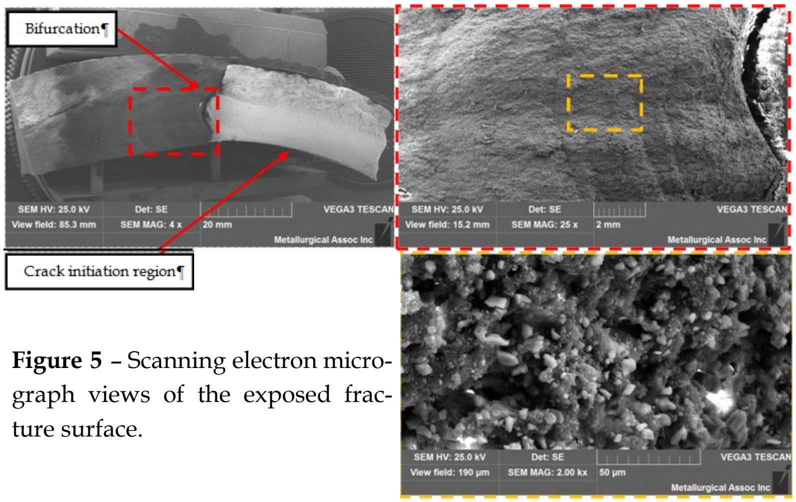


**Figure 5** – Scanning electron micrograph views of the exposed fracture surface.

Additional cracking on the First Layer was observed as a bifurcation of the main crack. Furthermore, two additional crack locations were identified on the First Layer at remote locations from the main crack (**Figure 3**). These cracks had only progressed through the First Layer of material. The progressive cracking may be an indication that after the cracks had propagated sufficiently to relieve stress, continued cracking occurred through low cycle fatigue associated with subsequent bouncing of the medicine ball.

Through Scanning Electron Microscopy (SEM), it was possible to observe the progressive cracking features and significant amounts of filler material in the First, Second and External Layers (**Figure 5**). The high magnification views did not reveal additional features on the crack progression through the materials in the medicine ball.

Analysis of the materials in the medicine ball via Differential Scanning Calorimetry (DSC) produced very similar results. The thermograms indicated that the materials underwent endothermic events that covered a broad temperature range, centered at approximately 90 °C during the first heating run. The totality of the DSC results obtained for the medicine ball components were indicative of thermoset materials. The thermal events were thought to be attributed to the continued curing of the thermoset resins (**Figure 6**).

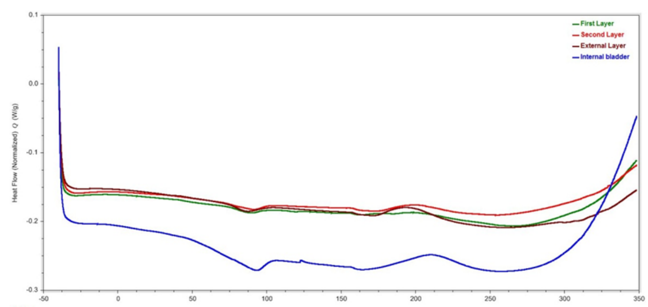


**Figure 6** – Initial heating DSC thermogram of the components of the medicine ball.

The Fourier Transform Infrared Spectroscopy (FTIR) spectra obtained for the components of the medicine ball indicated that the internal bladder and the First, Second and External Layers of material consisted of styrene-butadiene based materials. Furthermore, the spectra showed absorption bands characteristic of calcium carbonate (CaCO3), a common filler in rubber formulations (**Figure 7**).

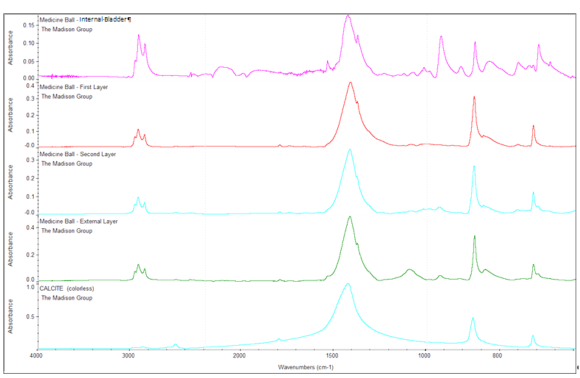

**Figure 7** – FTIR spectra of the components of the medicine ball. Each of the components exhibited absorption bands characteristic of styrene-butadiene based materials. Furthermore, the spectra showed absorption bands characteristic of calcium carbonate.

On comparing the thermogravimetric analysis (TGA) results for the various layers in the medicine ball, it can be seen that both the internal bladder and the First Layer decomposed in a

 

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similar manner. Similarly, the Second and External Layers of the material showed comparable TGA profiles. The initial weight loss observed across the TGA profiles for all of the materials, was associated with the volatilization of hydrocarbon-based plasticizers within the material's formulation. The test also showed that the material for the First, Second and External Layers were identified as having approximately 70% of filler content, while the material in the internal bladder showed filler content of approximately 26% (**Figure 8**). Based on the results from the FTIR testing, a larger portion of the filler content could be attributed to a calcium carbonate filler.

Based on the material analyses performed on the components of the medicine ball, it is likely the internal bladder was made out of an SBR rubber based material while the layers in the shell of the ball were likely, EPDM rubber-based materials.

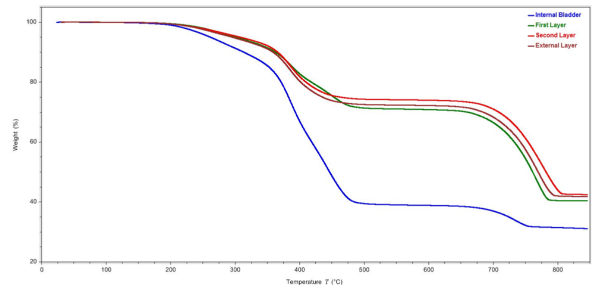


**Figure 8** – TGA thermogram of the components of the medicine ball.

### Conclusions

This analysis showed that the failure of the medicine ball occurred through a low cycle fatigue mechanism. This resulted in the development of a large crack that propagated through the First, Second and External Layers of elastomeric materials in the ball. Sectioning of the ball revealed evident variations in thickness throughout the shell of the medicine ball with cracking initiating at a region with reduced thickness. Given the unknown air pressure at the timeframe when failure occurred or the amount of stress and frequency for the applied stress, it is likely that a combination of these factors caused the failure of this piece of fitness equipment during use.

***Information regarding additional case studies can also be found at:***
***https://www.madisongroup.com/case-studies.html***

# Announcements: Newly Released

**Paul J. Gramann—Ph.D., P.E.**

**Designing a Plastic Part is More Than Skin Deep**
*March 20, 2019*

"Design is an all-encompassing term that involves nearly every facet of product success. Its preponderance in product development is often overlooked, however, and given neither the proper time nor effort that is required."

**Click here to read more…**

**Jeffrey A. Jansen—Sr. Managing Engineer** **ANTEC®**

**Failure Analysis of Automotive Air Conditioning Connectors**
*Jeffrey A. Jansen, The Madison Group, Madison, Wisconsin*

**Nominated for Best ANTEC® Paper in the Failure Analysis Division**

**Abstract**
"Failures occurred within automotive air conditioning system connectors. The cracking was observed within connectors that had been installed in automobiles, which were part of a durability testing program. Focus of this investigation was a determination of the nature and cause of the failures. The results obtained during the evaluation of the cracked connectors indicated that the failures occurred through a brittle fracture, slow crack initiation creep rupture mechanism of the material. However, the cause of the failure was severe molecular degradation as a result of the durability test program conditions. This paper will review the testing performed to characterize the failure mode and identify the cause of the cracking, while demonstrating the analytical procedures used in the investigation."

 

# Upcoming Educational Webinars

**Webinars provide a cost-effective way to expand your knowledge of plastics.**

Below is a list of the upcoming webinars presented by TMG Engineers:

**Thursday, April 25, 2019**—*Jeffrey A. Jansen*—SpecialChem
**DSC Interpretation Made Easy for Plastics Optimization**
10:00 AM (EST)

Boost your plastics developments by extending the use of Differential Scanning Calorimetry (DSC) beyond routine characterization towards performance optimizations. M*inimize additive interactions, fine-tune processing, avoid premature failure.*

DSC is a very powerful and versatile tool. Insufficient interpretation skills prevent you from taking advantage of the additional information (material condition, properties…) available for efficient optimization of your plastic material and prevention of premature failure. **Join this course to:**

- Optimize your plastic material & go beyond routine characterization by **better extracting, interpreting & using** DSC data...
- **Wisely predict performance** of your materials by linking it to changes in glass transition temperature, crystallization point, melting point…
- **Save time optimizing your plastics development** by getting an expert insight to overcome calibration, sample preparation, contamination issues...

Click here to register.

**Thursday, June 13, 2019** - *Jeffrey A. Jansen*—Society of Plastics Engineers
**An Introduction to Dynamic Mechnical Analysis**
Noon (EST)

**Dynamic Mechanical Analysis** (DMA) is a thermoanalytical technique that measures the stiffness (modulus) and damping (tan delta) of polymeric materials to assess the viscoelastic properties as a function of time, temperature, and frequency. Polymeric materials display both elastic and viscous behavior simultaneously, and DMA can separate these responses. Polymers, composed of long molecular chains, have unique viscoelastic properties, which combine the characteristics of elastic solids and Newtonian fluids.

As part of the DMA evaluation, a small deformation is applied to a sample in a cyclic manner. This allows the material's response to stress, temperature, and frequency to be studied. The analysis can be in several modes, including tension, shear, compression, torsion, and flexure. DMA is a very powerful tool for the analysis of plastics and can provide information regarding:

- Modulus
- Damping
- Glass Transition
- Softening Temperature
- Creep Behavior
- Stress Relaxation
- Degree of Cure

This webinar will provide an introductory look into DMA and how it can be applied to better understand plastic behavior, both long-term and short-term.

Click here to register.

***Information regarding upcoming educational opportunities can also be found at:***
***http://www.madisongroup.com/events.html***

# Upcoming Educational Webinars (cont.)/Plastics Course

**Thursday, September 12, 2019**—*Jeffrey A. Jansen – Society of Plastics Engineers*
**Understanding Plastic Failure Rate**
11:00 AM—NOON (EDT)

When a plastic part fails, a tough question is often asked, "Why are a limited number of parts failing?". This is particularly true with seemingly random failures at significant, but low, failure rates. Two aspects are generally linked to such low failure rates, multiple factor concurrency and the statistical nature of plastic failures. Failure often only takes place when two or more factors take effect concurrently. Absent one of these factors, failure will not occur. Plastic resins and the associated forming processes produce parts with a statistical distribution of performance properties, such as strength and ductility. Likewise, environmental conditions, including stress and temperature, to which the resin is exposed through its life cycle is also a statistical distribution. Failure occurs when a portion of the distribution of stress on the parts exceeds a portion of the distribution of strength of the parts.

This webinar will illustrate how the combination of multiple factor concurrency and the inherent statistical nature of plastic materials can result in seemingly random failures.

**Click here to register.**

**Thursday, December 12, 2019** - *Jeffrey A. Jansen* – Society of Plastics Engineers
**Failure Associated With Injection Molding**
11:00AM–NOON (EDT)

The injection molding process is one of the key characteristics that determines how a plastic part will perform in service. Manufacturers certainly attempt to avoid failure, but often unanticipated factors result in unexpected problems. The chances for a successful application can be significantly increased through preventative measures, including appropriate material selection, proper mold design, and process development. Even when appropriate actions are taken, failures can still occur. The evaluation of these failures provides an opportunity for learning. By understanding how and why a plastic component is failed, steps can be taken to prevent future occurrences. Case Studies will be presented to illustrate failures associated with the deficiencies from the injection molding process. The presented cases will illustrate how the failure analysis process was used to identify the failure mechanism as well as the primary factors responsible for the failures.
Click **here** to register.

***Information regarding upcoming educational opportunities can also be found at:***
***http://www.madisongroup.com/events.html***

# Plastics Course

**Monday-Wednesday, October 14-16th, 2019**—UW-Milwaukee at Milwaukee
Presenters: *Jeffrey A. Jansen, Dr. Antoine Rios, Dr. Javier Cruz, and Erik Foltz*
**Plastic Part Failure: Analysis, Design & Prevention**

Dive into a broad range of topics essential to understanding and preventing plastic failure. The most efficient and effective approach to plastic component failure is performing a systematic failure analysis following a scientific method. Someone once said, "If you don't know how something broke, you can't fix it," highlighting the importance of a thorough understanding of how and why a product has failed.

Click **here** for more information.

***If you are interested to have The Madison Group come and speak or provide training to your team, please feel free to contact us at info@madisongroup.com.***

# 'Beam Me Up, Scotty!' (*Welding With Lasers*)

*Patrick Mabry, M.S.*

Leaps and bounds in technology have helped bring significantly advanced manufacturing opportunities within reach for many tool shops and molders. One of these advanced processes is Through Transmission Laser Welding (TTLW). What used to require a large capital investment has now become more accessible and affordable through the improvements of automation and optics technology.

Through Transmission Laser Welding involves passing an infrared (IR) laser beam over two plastic components that need to be bonded or welded together. The operating wavelengths for these lasers range from 800 to 1,050 nm [1]. As the IR laser beam passes over the two plastic pieces in contact, the top piece allows for transmission of the laser through its thickness, with no absorption of energy. The parts placed on top of the assembly, during welding, are generally transparent. Allowing the transmission of the laser through the top component is by intent, and is due to the fact that some polymers are not good at absorbing IR radiation. Once the beam passes through the top plastic component, it hits the lower plastic component in the assembly, which begins to absorb the IR radiation.

Hold the phone…didn't we just say that "some polymers are not good at absorbing IR radiation?" Then why does this lower part heat up?

In this process, an additive has been blended in with the polymer in the lower component. Often times, this additive is carbon black. By having this additive in the part, the material more readily absorbs IR radiation and generates enough heat to cause a melt state between the two components. This process is visualized in **Figure 1.**

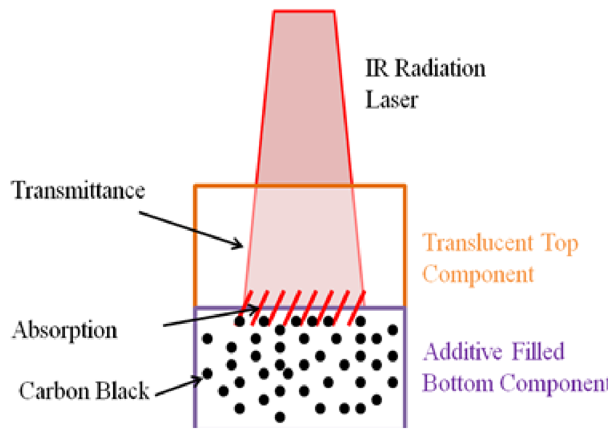


**Figure 1**—This image depicts the Through Transmission Laser Welding (TTLW) process with a translucent top component and a carbon black additive filled bottom.

The resulting weld is one that is extremely clean with little flash. There should also be very little residual stress carried by the parts or the weld joint itself, which is a concern with many welding processes. One noticeable advantage with this type of welding process, when compared to ultrasonic welding, is that the components never have to transfer high frequency energy throughout the part in order to generate a melt state at the weld site. This lack of mechanical stress on the part is advantageous since it lowers the risk of damaging the parts during the welding process.

There are several variations of TTLW, with each excelling at different types of geometry and weld joint designs. Not all materials are suitable for this type of welding. However, the materials that lend themselves to strong weld bonds through TTLW will be able to be incorporated into larger designs, with more free-form contours and complexities. These topics will be covered in the next installation of "*Welding With Lasers*."

*[1] Grewell, Benatar, Park, "Plastics and Composites Welding Handbook," (2003).*

***Information regarding additional articles can also be found at:***
https://www.madisongroup.com/articles.html