**Preventing Failures in Elastomeric Resistance Bands**

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### Abstract

The failure of an elastomeric resistance band used in performing physical exercises can often result in human injury. This paper investigates the cause(s) of failure and attempts to identify designs, materials, and manufacturing methods that can prevent failures in elastomeric resistance bands. This paper discusses three separate failure analysis case studies involving elastomeric resistance bands to identify failure modes. It also provides evaluation of six different elastomeric resistance bands to identify design, manufacturing, and material characteristics that are important in prevention of elastomeric resistance band failures.

### Introduction

There is increased use of elastomeric resistance bands among the variety of popular exercise programs available for physical fitness and rehabilitation. The elastomeric resistance bands do not take up much space, are easy to travel with, and allow the user to perform simple exercise routines. The concept is to stretch and pull an elastomeric resistance band to provide the force resistance required to help build or tone muscle. With increased use of elastomeric resistance bands, there have been increased instances reported of elastomeric resistance bands failures. The stored energy in the resistance band is released when the band fails, and the failure of elastomeric resistance bands while exercising has been known to cause personal injury. Incidents of broken bones, eye injury, face lacerations as well as loss of hearing have been documented. It has been reported that injuries have been sustained by politicians, professional athletes, health club members, physical therapy clinic patients, and household users of resistance bands. There have been a number of products that were subject to a recall by the U.S. Consumer Product Safety Commission (CPSC).

The resistance bands are generally comprised of a hollow elastomeric tube of rubber that is secured to a handle on each end. The handle is either a flexible fabric or a rigid plastic. Although simple in design, the primary function of the band is to provide resistance as it is stretched beyond its actual length. The stretch distance applied to the bands depends on the exercise routine.

In this paper three different failure analysis case studies are discussed involving three different resistance bands which allegedly caused injury to the user while performing routine exercises. The failures in the resistance bands examined in this study were found to have occurred in various components of the exercise band. Failures either occurred in the elastomeric band, the handle, and/or in the mechanism that attaches the band to the handle.

The failure investigations highlighted the importance of performance evaluation of various elastomeric resistance bands. Thus, six different bands each with unique design, manufacturing, and materials were tested to failure to identify their performance. The bands examined were commercially available elastomeric resistance bands. Tensile pull testing to failure was performed on the complete resistance band product to ensure that the failure identified the weakest component in the product.

### Literature Review

Previous research has studied failure modes of elastic bungee cords and their associated injuries [1-2]. The U.S. Consumer Product Safety Commission (CPSC) maintains a database on exercise resistance bands injuries through its National Injury Information Clearinghouse [3].
In addition, the medical literature has addressed eye injuries caused by released exercise resistance bands [4-6]. It has been reported that even professional sports athletes have sustained eye injuries associated with released resistance bands [7]. The patent literature has presented elastic resistance band design features to reduce the risk associated with failures and unintended release [8-12]. The authors did not find any industry acceptable guidelines or standards relating to the material specifications or performance requirement for the elastomeric resistance band product. The discussion of the findings reported in this paper attempt to highlight parameters that may be considered in development of such standards.

Determination of cause of failures in resistance bands

Case Study #1

Failure of a red colored elastomeric resistance band shown in Figure 1 caused injury to the user’s face while exercising. The resistance band is a 0.65 inch outer diameter tube (hollow inside) and has approximately a 0.13 inch wall thickness. The tube is attached to a rigid plastic handle. The plastic handle had also failed in this accident. The tube is connected to the handle by presence of a thick plug near each end that secures the handle as shown in Figure 1. A close up of the angle crack that caused rupture of the band is shown in Figure 1. There is evidence of small tears on the outer surface near the crack plane. Examination of the outer surface within few inches of the failure also showed the presence of nicks, cuts, and gouges to the outer surface as shown in Figure 2. Investigation into how the user was exercising revealed that the band was placed over a metal sprinkler pipe as shown in Figure 2. The fracture most likely occurred due to movement of the tubing over the rough surface of the pipe that caused small cuts in the tubing which failed when the tubing was further stretched by additional use. The handle most likely failed when it impacted the face of the user after the resistance band failed or at the very least was not a cause of the band failure. An inspection of the elastomeric band condition prior to use is important in safe use of any resistance band.

Case Study #2

A user of a resistance band sustained injury to his face when a plastic handle failed during exercising. The resistance band did not fail, but the handle broke during use. The overall appearance of the band and broken handle is shown in Figure 3. The cylindrical red-colored grip of the handled separated from the handle body. This style of resistance band handle allows the user to interchange and use up to three resistance bands together during exercising as shown in Figure 3.

A close up examination revealed that the grip pulled out of the handle due to cracks in the crown portion of the grip insert. The crack is shown in Figure 4. This section would be under tensile load during exercising. The fracture surface was not exposed for further examination. One potential is that the failure occurred due to a crack initiating from repeated use and loading of the handle. The handle was not strong enough to have three resistance bands used in combination. A single overload failure of the handle is also a potential.

Case Study #3

A user sustained an eye injury when a red colored elastomeric resistance band shown in Figure 5 failed at the connection between the handle and the resistance band. The hollow resistance band has an outer diameter (O.D.) of 0.48 inches and a wall thickness of 0.16 inches. The resistance band was part of a kit where the handles can be interchanged onto resistance bands of various resistances by a carabiner. The failure mode consisted of a black plastic ball releasing from inside the elastomeric hollow tubing. A 1.25 inch long segment of the elastomeric tubing fractured from the same end as the released interior ball. A
black O-ring also came loose from the outside of the elastomeric tubing at the failed end. Figure 5 depicts a close up of the failed end of the resistance band. The crack surface of the failed elastomeric tubing is displayed in Figure 6.

**Testing of Resistance Bands**

**Resistance Band Test Specimens**

Six commercially available elastomeric resistance bands were obtained. The resistance bands were chosen based on the different design elements and materials they offered.

Exercise band “A” is comprised of an elastomeric tubing that is inserted into a rigid plastic handle. The tubing can be easily replaced by simply pulling it out of the handle. A solid bulb is inserted after expanding the tubing on each end of the tubing and the design intent of the bulb is to keep the tubing from pulling out of the handle.

Exercise band “B” is identical to Exercise band “A” except for that the handle attachment is flexible and not rigid. The tubing is secured to the handle in the same manner as in Exercise band “A”. Additionally, the designers have provided three foam inserts that go over the elastomeric tubing. The design intent is to protect the elastomeric tubing from any damage during use and storage.

Exercise band “C” is different in that there is a sleeve that completely covers the elastomeric resistance band. The design intent of the sleeve appears to protect the elastomeric tubing from damage during use and storage, UV exposure, and overstretches of the elastomeric tubing.

Visually exercise band “D” is similar to “C”. However, this band is marketed as having patented Distance Governor Safety Anti-snap Technology. Although not visible below the nylon sleeve, inside the elastomeric tubing is a cord. This cord is designed to limit the stretch distance of the elastomeric tubing. This design will be discussed further in the results section.

Exercise band “E” is similar in appearance to “C” and “D” due to its outer sleeve which closes the ends of the interior elastomeric tubing. However, the main difference visible in the design was the use of metal carabiner components to secure the elastomeric tubing to the exercise handle. Based on the information provided by the manufacturer, multi-layered technology using natural liquid latex is present inside the sleeve to reduce the likelihood of failure. A photo of the cross-section of the elastomeric resistance band is provided in Figure 7.

Exercise band “F” does not have an outer sleeve, but it offers simplest design for interchanging the elastomeric resistance band by removing it from the carabiner attached to the flexible handles. Both ends of the elastomeric resistance bands are secured to a small loop of flexible strap by passing the bands through a circular opening on the bottom of the loop. The elastomeric tubing remains attached to the strap loop because a ball larger than the hole diameter is inserted on each end of the tubing.

**Experiment**

The overall dimensions of the six resistance bands are shown in Table 1 below. The resistance bands were generally half inch in diameter and approximately 60 inches (5 feet long). The material of the resistance bands (A, B, C, F) were identified using Fourier Infrared Microscopy. The samples were analyzed after pyrolysis. The Attenuated Total Reflectance mode was used on the pyrolyzate. The reference spectra for each resistance band is provided in Figure 8. A Biorad spectral library with over 250,000 spectra was used for identification purposes. The best match material was polyisoprene.

In order to measure the load required to cause failure of the weakest component in each design and to determine the maximum stretch at failure, each of the resistance bands were fixed on one end and pulled in tensile loading until failure. The testing was conducted under ambient conditions. The exercise bands stretched as a result of the
forced pull and the load required for the failure was recorded utilizing a 2000 pound capacity load cell connected to a National Instrument signal express data acquisition system equipped with a National Instrument 9215 analog to digital converter board. The load cell was checked for calibration prior to every experiment. The pull rate was not recorded but an attempt was made to keep the rate constant for each of the tests. The load versus pull distance capability of each resistance band is plotted and shown in Figure 9. The overall appearance of each resistance band tested and where the failure occurred is shown in Figures 10-15.

Discussion of Results

The testing revealed that the weakest design element in resistance bands can vary and failures in some resistance bands can occur at pull distance of 10 feet and at loads that are possible to exert during exercising.

Review of anthropometry and biomechanics data [13] in Human Factors Design Standard showed that standing with feet apart, knees bent, and bending at the waist, the peak force for two handed pull ranges from 90-200 lbs for 5th and 95th percentile females, respectively and ranges from 190-323 lbs for 5th and 95th percentile males, respectively.

Exercise bands A, B, D, and F failed well below the forces that can be exerted in a two handed pull. The testing also revealed that the designs of exercise bands C and E have stretch limiters at approximately 10 feet of stretch where the load required for any additional elongation is so high that it would alert the user that maximum pull distance is reached.

Furthermore, in the elastomeric resistance band C there was no failure of the elastomer tube and there was no snap back. Similarly, there was no failure of the elastomeric tube in resistance band E. In this sample, the sleeve is secured such that it limits the stretch, and the use of metal carabiner requires a load of 700 lbs. for the band to separate from the handle. Such loads provide fail safe mechanism as they exceed the capacity of the user.

Conclusions

The failure of elastomeric resistance bands can occur from tearing of the elastomeric resistance band, failure of the plastic handle, or by failure of the attachment mechanism that secures the band to the handle. A simple foam sleeve that is movable across the elastomeric resistance band does not appear to be an adequate solution to prevent damage to the elastomeric resistance band to prevent failures and snap back. A strong permanent sleeve made of nylon webbing appears to increase the load required to failure and limits the travel if it is properly secured to the handles. Another design approach to limit the snap back is to include a cord that runs inside the hollow elastomeric resistance band. The design solutions that limit the pull distance, protect the elastomeric sleeve, and have high loads to failure can prevent failures of resistance bands. The use of metal material components in methods of attachment of the bands to the handle also increases the load capacity of the bands.

Some elastomeric resistance bands place on-product warnings and resistance strength limits on the handles, which can also assist in preventing injuries. Finally, some elastomeric resistance band suppliers recommend the use of safety eyewear as an eye injury prevention strategy.

In the absence of any industry accepted design standards, the information in the Human Factors Design Standard may be used as guidelines of the strength performance requirements of resistance bands. The methodology utilized in this paper is intended to contribute to the literature regarding use, design, manufacture, and failure prevention of resistance bands. The data and interpretation analysis can serve as a guideline for evaluating performance characteristic of resistance bands to prevent their failures.
Acknowledgement

The authors would like to thank Robert R. Franzese for his assistance in photo documentation of the resistance bands analyzed in this investigation.

References

Figure 1. Overall appearance of failed elastomeric resistance band (Left). Close up of crack in elastomeric tube that caused failure (Right). (Case Study #1)

Figure 2. Additional nicks, cuts, and gouges were also found near failure location (Left). Photo showing the way elastomeric resistance band was being used at time of accident (Right). (Case Study #1)

Figure 3. Overall appearance of second failed resistance band (Left). Failure occurred in grip portion which separated from plastic handle. This style handle has options to interchange and use up to three resistance bands together (Right). (Case Study #2)
Figure 4. Failure occurred due to crown of grip insert developing a crack and caused grip to separate and hit user. (Case Study #2)

Figure 5. Failure of elastomeric resistance band. Close-up of failed end of elastomeric resistance band. (Case Study #3)

Figure 6. Close-up of failed end of elastomeric resistance band. (Case Study #3)
Figure 7. Multi-layered technology using natural liquid latex elastomeric resistance band. Image provided by manufacturer. Layered technology is to stop a tear before it reaches next layer in attempt to eliminate band failure and snap back.

Figure 8. FTIR analysis for material identification of four elastomeric resistance bands. All four were identical and were identified as manufactured using polyisoprene rubber.
Figure 9. Testing results of six different exercise bands.

Figure 10. Rigid handle and attachment mechanism of exercise band “A” (Left). Failure is at handle attachment point. Failure occurred at 70 lbs.

Figure 11. Flexible handle, foam insert, and attachment mechanism of exercise band “B” (Left). Failure is at handle attachment point and occurred at 125 lbs.
Figure 12. Foam grip flexible handle and attachment mechanism of an outer full length sleeve on exercise band “C”. Band stretch was limited by outer sleeve. Sleeve tore at 300 lbs. of tensile load and no failure was observed in the elastomeric tubing.

Figure 13. Flexible handle and attachment mechanism of exercise band “D”. Failure occurred at both attachment ends. Stretch of band was limited by cord inside tubing. Failure occurred at 190 lbs. of tensile load.

Figure 14. Outer sleeve, flexible handle, metal carabiner, and the metal ring attachment mechanism of exercise band “E”. Failure occurred in handle steel ring. Failure occurred at 700 lbs. at a stretch distance of 17 feet.
Figure 15. Flexible handle, metal carabiner, and attachment mechanism of exercise band “F”. Failure occurred at 56 lbs. by ball securing band to strap-hook pulling out of band. Stretch distance was 17 feet.

Table 1. Overall dimensions of six tested exercise bands.

<table>
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<tr>
<th></th>
<th>O.D.</th>
<th>Wall Thickness</th>
<th>Length</th>
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<tr>
<td></td>
<td>(inches)</td>
<td>(inches)</td>
<td>Rubber (inches)</td>
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<tr>
<td>A</td>
<td>0.480</td>
<td>0.119</td>
<td>61</td>
</tr>
<tr>
<td>B</td>
<td>0.448</td>
<td>0.116</td>
<td>61</td>
</tr>
<tr>
<td>C</td>
<td>0.435</td>
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<td>48</td>
</tr>
<tr>
<td>D</td>
<td>0.527</td>
<td>0.140</td>
<td>59</td>
</tr>
<tr>
<td>E</td>
<td>N/A</td>
<td>N/A</td>
<td>50</td>
</tr>
<tr>
<td>F</td>
<td>0.475</td>
<td>0.158</td>
<td>51.5</td>
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Table 2. Load-to-failure and stretch distance-to-failure.

<table>
<thead>
<tr>
<th></th>
<th>Load (lbs.)</th>
<th>Distance (feet)</th>
<th>Stretch Ratio</th>
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<tbody>
<tr>
<td>A</td>
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<td>25</td>
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</tr>
<tr>
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</tr>
<tr>
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<tr>
<td>F</td>
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