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BEFORE THE
POSTAL REGULATORY COMMISSION
WASHINGTON, D.C. 20268-0001

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| COMPLAINT OF GAMEFLY, INC. | Docket No. C2009-1 |

# DIRECT TESTIMONY OF

# ROBERT LUNDAHL

# ON BEHALF OF THE

# UNITED STATES POSTAL SERVICE

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**Autobiographical Sketch**

My name is Rob Lundahl. Currently, I am Vice President of the Automated Systems Division at Advanced Technology and Research Corporation ("ATR").

I hold a Bachelor of Science degree in Mechanical Engineering from Western Michigan University and have over twenty-five years of engineering experience. Most of my career has been focused in smaller research and development organizations where I have contributed in a wide range of technical disciplines. I have served as the quality assurance manager for military customers, and established the companies QA system for MIL-I-45208, MIL-Q-9858, and ISO 2001 certifications. As a project engineer I have worked with the Army, Navy, Air Force, and NASA developing a wide variety of one of a kind devices.

I have worked on Postal Service projects over the entire course of my career. These projects have included several failure analysis studies of parts and mechanisms in mail sortation. While at ATR, I and my colleagues have served the Postal Service as a primary supporter of Research & Development activities that have led to the development of many fielded pieces of Postal Service equipment. I was the program manager that developed the first mail tray handling applications at the Postal Service and established the performance parameters for the fielding of these robotic work cells that represented the largest purchase of robotics outside the automotive industry.

## Purpose of Testimony

My testimony addresses two areas: (1) the fundamental qualities and differences among DVDs, including gaming, movie, standard definition and Blu-ray DVDs; and (2) actions mailers can take to manage or reduce damage to both DVDs and Postal Service equipment incurred during automated or manual processing of DVD mail.

## Introduction

DVDs are not all the same. Beyond the basic "sandwich" design of standard DVDs, and the "open-faced sandwich" design of Blu-ray DVDs, they vary across parameters that affect their flexibility, durability, and resistance to bending, breaking, impact or scratching. These variations affect the consequent damage that could occur during preparation for mailing, outbound transit via the mail, handling by consumers who access content, preparation for transit through the mail on a return trip, and subsequent transportation and handling by the originator and ultimate recipient. When in transit through the mail, DVDs face the risk of damage from mail processing that proper set up, adjustment, and maintenance of mail processing equipment can help control. These variations, depending upon how discs are engineered, can be used to engineer discs that minimize the risks of particular kinds of damage. DVDs face risks of damage from various types of processing depending, for example, upon the mechanical twists, impacts and turns a particular piece of equipment imparts. It is also true that any single processing path does not impose the same risks on all DVDs.

The mechanical risk is the same. However, all DVDs are not equal. A more fatigue-resistant DVD will not be affected the same.

As described below, the type of DVDs mailed by GameFly and the methods GameFly uses to mail those DVDs may make the DVDs shipped by GameFly more susceptible to damage than the DVDs shipped by Netflix, and perhaps other DVD mailers. This conclusion stems from the fact that GameFly has no real understanding of the physical traits of DVDs beyond their thickness, and to my knowledge they have not conducted a detailed study of DVD failure modes and mechanisms. By way of contrast, Netflix has studied DVDs, and their structure and composition, so that it can mail DVDs engineered to minimize risk of breakage or damage on a round trip, or sequence of round trips, through the mail. As explained in greater detail in this testimony, analysis leads me to conclude that GameFly is not similarly situated to Netflix, and likely also other DVD mailers, with respect to the DVDs it mails, and that GameFly DVDs face a much greater risk of damage than DVDs mailed by other DVD round trip mailers. GameFly's apparent lack of understanding of the nature of DVD failure undermines any credibility for its assertions that it is similar to Netflix or other DVD mailers. GameFly effectively has no idea how its DVDs incur damage, and any claim to the contrary lacks credibility.

In my experience, DVD mailers can work with manufacturers or sellers to design DVDs with properties best suited for transit through the mail. They can do this, either with DVD vendors directly, or by working through their respective

manufacturers, whether they work for creators of content or vendors of DVDs such as Netflix or GameFly.

## I. Qualities and Differences of DVDs

All DVDs do not share a common set of qualities and characteristics. DVDs differ in a variety of ways, including coating, structural composition, modulus of elasticity, brittleness, and ability to withstand impact and twisting force imparted by objects of various shapes and strengths. These differences affect how they may be played, data storage, how data are read, proper storage, and, most importantly for my testimony, their susceptibility to various possible sources of damage.

Over the last 15 years, my division within ATR, a specialized engineering firm, has worked as a contractor for Postal Service Engineering to design and develop new mail processing equipment, work out solutions to particular challenges, or otherwise provide mechanical engineering services. Finite element analysis is one tool that has helped us figure out specific challenges with complex stress patterns requiring analysis. Most of this work was mechanical in nature and required a broad experience in mail handling technologies and Postal Service material handling systems.

More recently, my firm was retained by Netflix to analyze DVD breakage. This research looked at the various modes and studied the mechanisms that could have caused damage. ATR started with an initial classification of failure modes and visually inspected thousands of failed DVDs. It was evident from the beginning that the vast majority of standard definition DVD failures were the

result of cracks forming from the inside diameter and extending outwards into the read area. However, the Blu-ray failures were distinctly different. Blu-ray discs predominantly failed with cracks starting from the outside diameter and propagating inward to the read area. Clearly, this was a totally different process at work than the standard definition DVD. Many other odd ball failures were observed for both types of discs, and these were categorized as more random from scratching, mis-use, bending or other cracking.

The two common modes of failure were designated as material fatigue failures and mechanical impact failures, and these were generally divided between the standard definition DVDs and Blu-ray DVDs accordingly.

Fatigue failures from repeated bending were the most common mechanism leading to failure in standard definition DVDs. Fatigue failures are not absolute breakage mechanisms such as a mechanical impact or cutting. Fatigue is accumulated over time and is assessed statistically. As a result, this research required a great deal of destructive testing that ATR performed on specialized fatigue mechanisms that ATR designed to simulate the bending stress that the DVDs experience on their path through the mail processing equipment. The test results were more statistical failures, rather than absolute fail/no fail tests

In the end, the vast majority of standard definition DVD failures are caused by the repeated bending stresses from mail handling equipment; however, most material will fatigue and break when subjected to these conditions. Repeated bending causes material fatigue and the formation of small micro cracks.

Continued bending cycles causes these cracks to propagate until they extend into the read area, and the playability of the disc is compromised. This was the primary mode of failure for standard definition DVDs and a fundamental challenge for processing on the current design of mail handling equipment, as this equipment was not designed to process DVDs in mind but has processed other envelopes without difficulty.

Understanding these fatigue related failures led to several recommendations for Netflix to increase the fatigue life of their standard definition DVDs and effectively increase their productive life. Key manufacturing steps, cutter quality, material quality, UV exposure, and localized reinforcements were some of the techniques adopted by Netflix to increase the fatigue life of their DVDs.

A different mode of failure was observed for Blu-ray DVDs. This mode of failure was a mechanical impact failure on the outside diameter of the DVD. The vast majority of Blu-ray DVDs exhibited this same form of failure. These failures arose generally on the letter processing side and showed a higher geographical concentration. This type of failure was an impact failure and traced to missing pads or bumpers in mail sorters, incorrectly adjusted finger guards, and other misaligned equipment that interfered with the mail flow path. These sources of failure were observed and replicated on key equipment. These failure points were generally not the norm and the result of some sort of outstanding maintenance issue. It is my understanding that the Postal Service has made modifications to resolve these issues.

ATR provided the results of our research to Netflix, offered several recommendations regarding the manufacture of DVDs, and identified specific mail processing equipment that could cause damage if not properly maintained. While some details of this work remain confidential and proprietary to Netflix, I am free to share details that form the content of my testimony.

Based on this background, my knowledge and experience, I identify, below, the most important qualities and differences among DVDs, how the manufacturing of DVDs can minimize mail processing damage, and opportunities for improvement of mail processing equipment, all of which Netflix has wielded in efforts to contain or minimize damage caused by the processing of its mailpieces on Postal Service and others' processing equipment.

**A. Inside Diameter Hole**

My experience reflects that DVDs are consistent in the size and roundness of their inside diameter holes. However, there are subtle differences in the quality of the punched hole. A cleaner inside diameter hole results in more durability, reduced damage, and more accurate playing.

Our analysis of processing equipment showed the many bending stresses to which the DVDs are subjected. ATR performed a Finite Element Model (FEM) to study these bending stresses and see where there were stress concentrations in the DVD. (See appendix ATR1). From this analysis it was evident that the center hole was a major concentration of stresses and this correlated with our observations of where cracks start to form in the polycarbonate materials.

Cracks form where there is the highest stress and this can be initiated by a very localized stress concentration. ATR performed extensive testing on a specially designed fatigue machine (See appendix ATR 2) and determined that there was a correlation with the quality of the hole cut in the center of the DVD. Holes cut with a new, sharp cutter, showed a far better fatigue life in that they could withstand many more bending cycles before cracks would begin to form around the inner diameter.

In addition to cutter quality, ATR recommended a review of all other manufacturing processes where the inside diameter of the DVD hole would be touched and where it was possible to scratch the internal diameter and cause a stress concentration. (See appendix ATR 3 for summary test of new cutters).

**B. UV Curing**

DVDs undergo a wide range of ultraviolet (UV) curing. A greater amount of UV curing causes a DVD to be more brittle and more susceptible to damage because exposure to UV radiation changes the mechanical properties of polycarbonate materials and makes them more brittle and susceptible to fatigue. Generally, all DVDs manufactured for retail purchase have had some UV radiation exposure because of the bonding agents applied to UV cured DVDs. However, UV curing is also used in the printing process and used to harden each layer of color. Single color labels will have far less radiation than full color prints, since each layer has to be cured separately. Testing results were difficult to validate with the number of parameters that cannot be controlled. However, the damage to plastic caused by UV exposure is commonly understood, and Netflix

also understood the likely ramifications from too much UV exposure. Netflix reviewed its printing techniques and the exposure levels at all steps of the fabrication process. (See appendix ATR 4 for a summary chart of the improved printing techniques)

### C. Polycarbonate

The polycarbonate used in DVDs varies widely. DVDs composed of higher quality polycarbonate are more durable and less susceptible to damage. There are many kinds of polycarbonate plastics used in the construction of optical discs and, depending on the replicator, the polycarbonates can vary greatly. Different polycarbonate materials possess different mechanical properties that greatly affect their resistance to fatigue. Price, availability, and other market factors drive the replicators to select one polycarbonate over another, and what is used for DVDs cannot be assumed to be the same as what is used on games, given the replication and wholesale price differentials between the two “formats.” Other processing factors can further affect the mechanical properties, and these can have a profound effect on their overall performance.

The basic mechanical parameters for industry polycarbonates vary widely. Appendix ATR 5 shows representative data for three popular DVD materials in the form of Charpy impact tests. This test shows the relative amount of energy that is required to cause failure of a test specimen. The higher the energy required, the better this material should withstand mechanical stresses before failure. From this data, it can be seen that the Bayer MACRALON is nearly 15 times stronger than the Teijin Panalite. In addition, all of the polycarbonate

materials can have their mechanical properties change significantly based on how they are heated and dried before the actual injection process. Manufacturers have different specifications for how long the material is heated, and this will significantly affect the mechanical properties of the finished product.

### D. Replicators

I have noticed that DVD mailers use different replicators. The quality of these replicators varies, and thus the DVDs from different replicators have different levels of durability and susceptibility to damage. Because GameFly has stated that it purchases its DVDs from the manufacturers, it likely does not use replicators. The manufacturing process for DVDs is critical to their quality. Cutter quality, material quality, and process integrity are critical, as described above. Test results show that there can be a significant difference between machines, even at the same manufacturer.

Netflix has a significant investment in understanding all of the variances and certainly must appreciate how quality manufacturing impacts the long term quality of their DVDs. For example, recently Netflix has started using a new covering coat for their Blu-ray DVDs and a new adhesive in their standard definition DVDs. These newer materials have enhanced mechanical properties and have further increased the fatigue life of the newly manufactured DVDs.

### E. Structural Composition

Most DVD mailers mail both standard definition DVDs and Blu-ray DVDs. These two types of DVDs have different structural compositions, and face different risks of damage. Standard definition DVDs are constructed of two 0.6

mm pieces of polycarbonate glued together with the DVD being a single-sided, single layer disc holding up to 4.7 GB of data on a data layer. Blu-ray DVDs are constructed of a solid 1.1 mm piece of polycarbonate with the additional cover layer making up for the 0.1 mm differential of the standard definition DVD. The technology is also different, as a standard definition DVD uses 650 nm red laser wavelength as opposed to 405 nm blue laser for Blu-ray DVDs, and the Blu-ray DVD permits a much smaller, highly compressed pit to be etched on the media surface as compared with the standard definition DVD. Gaming and movie DVDs include both standard definition DVDs and Blu-ray DVDs. For example, the wii and Xbox platforms incorporate standard definition DVDs, while the Sony Playstation platform utilizes Blu-ray DVDs.

The mechanical characteristics of standard definition DVDs are much different than Blu-ray DVDs in the thickness and placement of their layers. The predominant mode of failure for standard definition DVDs is from fatigue cracks forming on the inside diameter and propagating outwards. The predominant failure mode for Blu-ray DVDs is much different. Blu-ray discs fail from the outside diameter and propagate inwards. This is a much different mode of failure and indicates a different mechanism and cause.

ATR looked at impact failures as the predominant mechanism for the Blu-ray discs. After inspecting several Postal Service machines, ATR identified a finger guard that could extend into the mail flow path if it was missing its spring or was otherwise not aligned as it was designed. This source of failure would be experienced on the outgoing mail flow and only at select sort points and on a

couple versions of the postal DBCS machines. These failures were also dependant on the orientation of the DVD in the envelope. It is my understanding that the Postal Service has made modifications to resolve these issues.

## II. Actions Available to Reduce Damage to DVDs and Postal Service Equipment

I have worked with the Postal Service on projects related to its automated processing operations, and, as part of these projects, I have conducted testing and observations related to automated processing operations. As described above, a key adjustment was identified in several versions of the DBCS machines that resulted in much of the Blu-ray DVD damage. Other potential factors that could impact damage levels in general are bumper pads and belt tension. Properly maintained and adjusted machines will always improve their efficiency and safe processing of mailpieces.

Many mailers have taken actions to reduce or even avoid the risks of damage described above without changing the type of mail processing they receive. I describe some of the more successful practices below. Notably, GameFly's interrogatory answers suggest that GameFly is not aware of these options, and has not taken affirmative action to reduce the vulnerability of its DVDs to damage.

### A. Reinforcement Rings

Some mailers equip their DVDs with reinforcement rings on the inside diameter. ATR evaluated the use of reinforcement rings with an FEM study and later with actual destructive testing. We discovered that the reinforcement rings will reduce the rate of crack formation on the inner diameter and also slow the

rate of propagation from successive bending. Collectively, this increases the number of cycles the disc can withstand before failure, and therefore increases its service life.

### B. DVD Handling

DVD mailers utilize different methods of accepting DVDs from a manufacturer, and these differences can influence a DVD's susceptibility to damage. As described earlier, any nicks or scratches on the inside diameter of DVDs will increase their susceptibility to crack formation, leading to propagation, and eventual failure from repeated bending. Protecting the quality of this inside diameter is very important. DVDs are generally handled on spindles inside the manufacturing operation. ATR has identified this as a potential area where scratches could be formed on the inside diameter of the DVDs and recommended that these spindles be inspected and the manufacturing process should avoid excessive handling by the inside diameter or the use of jewel cases. Appendix ATR 6 shows a photomicrograph of the inside diameter and the types of scratches that can lower fatigue life.

### C. Orientation

The orientation of a DVD inside a mailpiece affects the DVD's susceptibility to damage. When a mailer orients its DVD on the leading edge of a mailpiece, the leading edge and the DVD experience a heightened level of pressure. This increases the likelihood of damage. However, Netflix orients its outgoing DVDs on the leading edge, and generally its DVDs do not suffer damage from the automated letter equipment if properly adjusted. Damage

assessments bear this out, since leading edge damage would cause cracks to form from the impact site on the outer diameter. This was true with the Blu-ray discs on a mis-adjusted sorter. However, this is not a usual mode of failure. Fatigue related cracks from the inside out are the dominant mode of failure for DVDs.

**D. Transportation**

I am aware of a broad range of transportation strategies used by DVD mailers. Generally, more handling results in a higher likelihood of damage. This includes both internal handling, and handling within the Postal Service network. Netflix has succeeded in reducing the amount of handling by developing automated internal handling processing and requiring minimal handling of its DVDs within the Postal Service processing network. Netflix has achieved this result by increasing the number of locations where it picks up and enters its mail (I believe it now uses 130 locations). In contrast, GameFly enters and picks up its mail at far fewer locations. Regardless of the type of processing a mailer receives, more handling will increase the risk of damage. This is an important strategy in minimizing DVD damage and reflects an understanding of bending fatigue as the primary source of failure. Minimizing the number of sorts minimizes the number of paths through the sorters, and minimizes the number of bends that the DVD is subjected to. This slows the rate of fatigue and increases the number of rental cycles before fatigue sets in.

### E. Envelope

Mailers use a range of envelopes. Some mailers, like Blockbuster, use a mailer that closely fits the size of a DVD; others, like Netflix, use a mailer that has a floppy edge; and still others, like GameFly, use an oversized mailer that more closely resembles a flat shape. The location of flaps, the strength of the paper and any inserts, and the distribution of material affect how a DVD is impacted by automated processing. Mailpieces without floppy edges, like those entered by Blockbuster, are less likely to jam Postal Service equipment and suffer the type of damage that could result from jams. More thickness in the leading edge of a mailpiece tends to reduce the amount of damage, as the leading edge experiences the most pressure during automated processing. Because GameFly enters its DVDs as flats, and most DVD mail is entered as letters, I cannot evaluate GameFly's envelope in this category. In general, the Postal Service processes outgoing Netflix mail on automated letter processing machines, and, despite the floppy trailing edge, for the most part this mail travels through the Postal Service equipment without damage. Understanding that most DVD failures are fatigue failures, reducing the number of bending cycles or the amount of stress in a bending cycle is a key strategy. The use of stiffeners inside the envelope would be a promising strategy to minimize the severity of the bend for the DVD itself. The degree of bend is directly proportional to the stress it receives. Using a stiffener could improve the fatigue life of a DVD without impacting the current machine with existing bend angles.

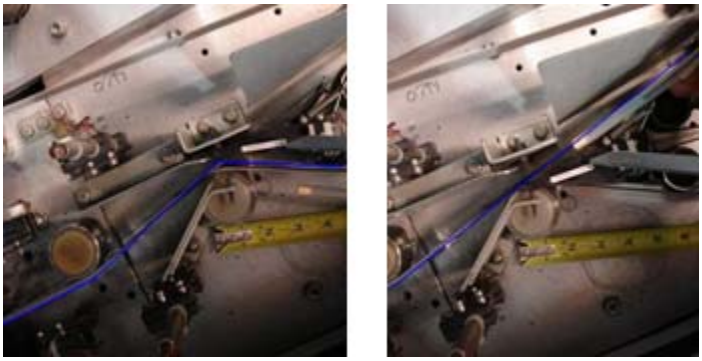
## Conclusion

As described in my testimony above, DVDs vary in their nature and composition and, accordingly, in their susceptibility to damage. Mailers have available many options to take affirmative action that reduces the susceptibility of their DVDs to damage. As explained above, Netflix and other DVD mailers mail DVDs with inherent characteristics that make DVDs more durable. They also take other actions that make their DVDs less vulnerable to damage, including the use of reinforcement rings, maintaining good cutters, maintaining spindle quality, and limiting the handling of their DVDs. GameFly mails DVDs that may be more susceptible to damage, since it does not take affirmative action to make its DVDs more fatigue resistant. GameFly appears to lack basic knowledge about DVDs, why they fail, and how to increase their fatigue life. GameFly's blanket statements regarding how its DVDs compare to other DVD mailers have no credibility without a careful accounting of what remedial actions have been taken to control materials and process.

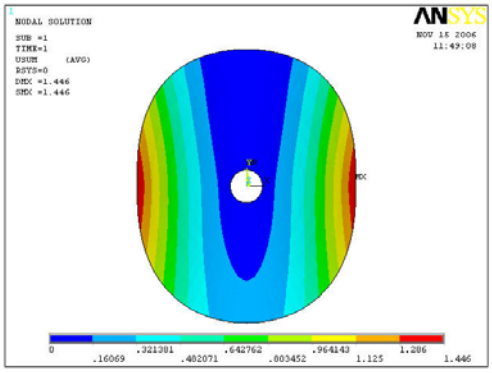
# APPENDIX ATR 1

# Appendix ATR 1

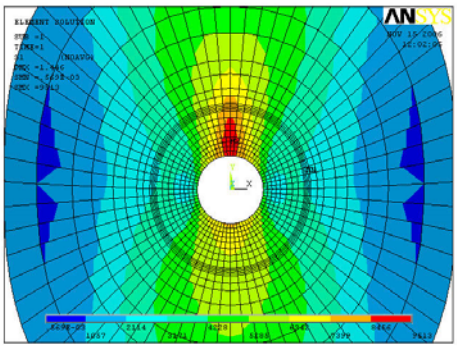
Finite Element Model
Close up of stress concentrations on the inside diameter



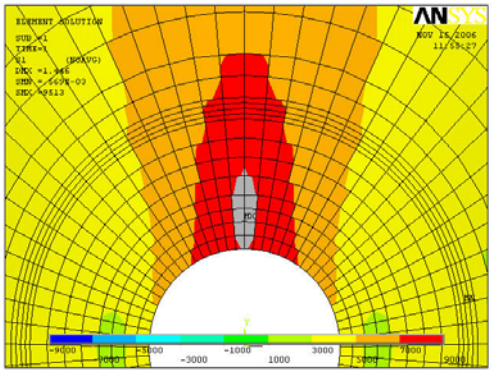
Actual mail path analysis




Model of disc bent around pinch belt sort roller




Close up of stress concentrations at center



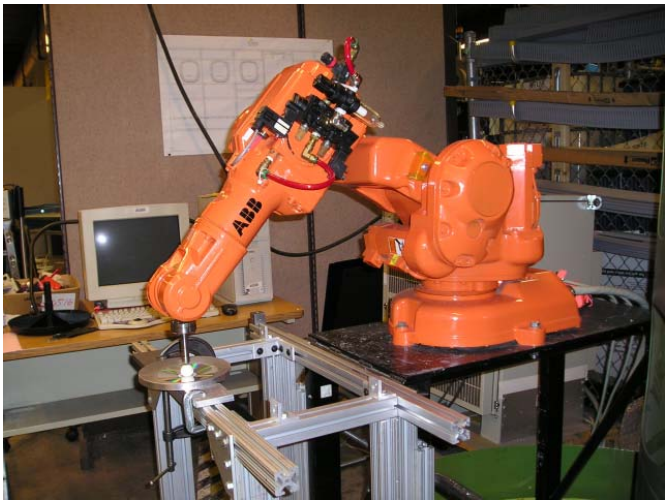

Highest concentration at top of ID in the mail path orientation

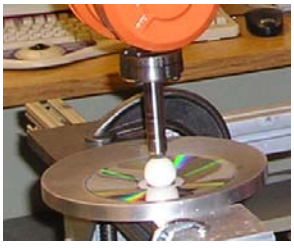
# APPENDIX ATR 2

## Appendix ATR 2

Specialized fatigue mechanisms used by ATR to evaluate fatigue life in the laboratory.

Reciprocating fatigue device to simulate pinch roller transport



Robotic Hoop Stress fatigue testing.
Provides omni-directional fatigue test

# APPENDIX ATR 3

# Appendix ATR 3

Summary test result
New cutter vs Old cutter used in DVD manufacture.

| Summary results from Hoop fatigue testing | Earlier Baseline - no printing | | | | | |
|---|---|---|---|---|---|---|
| | Old Cutter | | | New Cutter | | |
| | L1 up | L1 dwn | Avg | L1 up | L1 dwn | Avg |
| Average when cracks start (when we can see anything at all) | 405 | 500 | **453** | 385 | 415 | **400** |
| Average when cracks > 0.050 | 615 | 850 | **733** | 900 | 1030 | **965** |
| Average span between starting and final crack >0.050 | 210 | 390 | **300** | 515 | 615 | **565** |
| Average when the final crack starts | 495 | 695 | **595** | 690 | 850 | **770** |
| age of the time when final crack starts to when it grows > 0.050 | 120 | 160 | **140** | 210 | 180 | **195** |
| Average number of total cracks when finished | 14 | 11 | **12** | 27 | 23 | **25** |
| DVD that failed with catastrophic cracks | 2 | 2 | **2.00** | 0 | 0 | **0.00** |
| Reversing Stress cycles | | | | | | |

# APPENDIX ATR 4

# Appendix ATR 4

Summary test result
Improvements in printing techniques.

| Summary results from Hoop fatigue testing | New Data - Comparison of different printing techniques | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Old / Pantone | | | New/Pantone | | | Old/5 color offset | | | New/5 color offset | | | Old/5 color screen | | | New/5 color screen | | |
| | L1 up | L1 dwn | Avg | L1 up | L1 dwn | Avg | L1 up | L1 dwn | Avg | L1 up | L1 dwn | Avg | L1 up | L1 dwn | Avg | L1 up | L1 dwn | Avg |
| Average when cracks start (when we can see anything at all) | 413 | 444 | **428** | 513 | 669 | **591** | 556 | 606 | **581** | 569 | 569 | **569** | 631 | 594 | **613** | 519 | 519 | **519** |
| Average when cracks > 0.050 | 644 | 600 | **622** | 1131 | 1306 | **1219** | 738 | 775 | **756** | 950 | 1156 | **1053** | 869 | 769 | **819** | 719 | 806 | **763** |
| Average span between starting and final crack >0.050 | 231 | 150 | **191** | 619 | 770 | **694** | 181 | 170 | **176** | 381 | 510 | **446** | 238 | 150 | **194** | 200 | 250 | **225** |
| Average when the final crack starts | 538 | 494 | **516** | 838 | 1138 | **988** | 644 | 700 | **672** | 800 | 788 | **794** | 725 | 650 | **688** | 638 | 644 | **641** |
| age of the time when final crack starts to when it grows > 0.050 | 106 | 120 | **113** | 294 | 190 | **242** | 94 | 80 | **87** | 150 | 320 | **235** | 144 | 80 | **112** | 81 | 160 | **121** |
| Average number of total cracks when finished | 12 | 8 | **10** | 15 | 15 | **15** | 10 | 10 | **10** | 9 | 13 | **11** | 8 | 6 | **7** | 9 | 14 | **11** |
| DVD that failed with catastrophic cracks | 2 | 0 | **1.00** | 0 | 0 | **0.00** | 3 | 0 | **1.50** | 0 | 0 | **0.00** | 4 | 0 | **2.00** | 0 | 0 | **0.00** |

| Reversing Stress cycles | | | | | |
|---|---|---|---|---|---|
| | < best in category | | < Worst in category | | |
| | < best in sub category | | < Worst in sub category | | |
| | | | < poor | | |

# APPENDIX ATR 5

**Appendix ATR 5**
**Different mechanical properties for Polycarbonates**

# Notched Charpy Impact Test Results

| Material | Notched Charpy Impact Value |
|---|---|
| Bayer Material Science Makrolon OD2015 | 45 kj/$m^2$ or 21.41 ft-lb/$in^2$ |
| GE Lexan OQ 1030 | 14 kj/$m^2$ or 6.66 ft-lb/$in^2$ |
| Teijin Kasei America Panlite AD-5503 | 3 kj/$m^2$ or 1.43 ft-lb/$in^2$ |

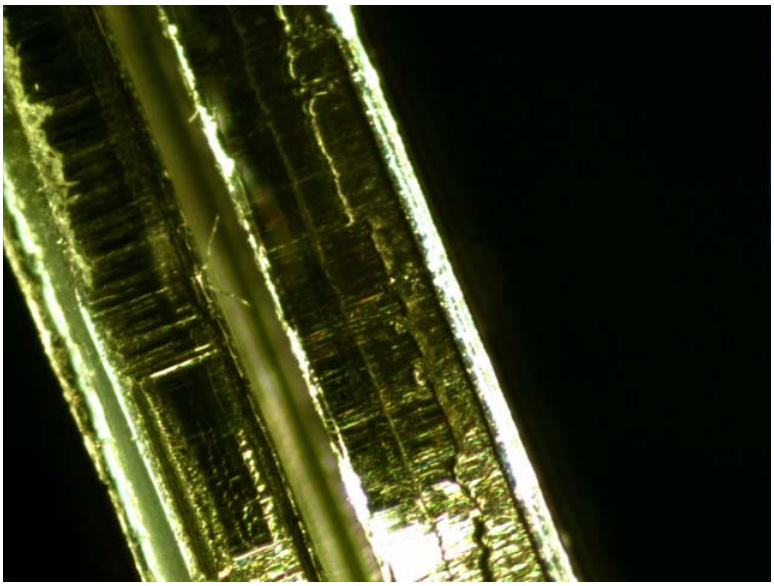
It appears that the Bayer Polycarbonate material is much tougher than the GE or Teijin Kasie America materials. Depending on cost and availability the Bayer material would be the material of choice to make the DVD's from. You should get many more cycles of use before you would have to retire the DVD from service.

# APPENDIX ATR 6

## Appendix ATR 6

Photomicrographs of DVD Inside Diamteres

Cutter marks



Surface defects