Durability Tests for the LabeLase® 1000 Tag Printer Technology

Final Report

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EXECUTIVE SUMMARY

Bruno Associates, Inc., expressed an interest in acquiring performance data for laser-marked bar code tags printed with the LabeLase® 1000 Tag Printer Technology. Specifically, Bruno Associates was interested in evaluating the performance of this technology after exposure to a variety of environmental conditions.

In response to this need, the Department of Industrial and Manufacturing Engineering (IME) at Oregon State University (OSU) performed this evaluation as an independent third party to ensure data objectivity. LabeLase® tags were encoded with two Data Matrix symbols and a single Code 39 bar code symbol to perform the evaluation.

A total of seven tests were carried out on the LabeLase® tags. Four tests were selected from the MIL-STD-810F document:

- 501 – High Temperature
- 504 – Contamination by Fluids
  - Hydraulic fluid
  - Diesel fluid
- 509 – Salt Fog
- 521 – Icing/Freezing Rain

Three additional tests (not included in the MIL-STD-810F document) were also selected:

- Abrasion
  - Very Fine 220 Grit Sand Paper
  - Medium 80 Grit Sand Paper
  - Coarse 40 Grit Sand Paper
- Impact Test
- Ultraviolet Light Exposure

It was determined that to guarantee the two probability requirements given in equations (1) and (2) in Section 1.4 with a 90% confidence level, a sample plan with a minimum sample size of n = 34 was needed. Therefore, 34 LabeLase® tags were requested from vendors that either manufacture or distribute these products. An additional 5 tags per product family were also requested to replace any tags that may have been damaged prior to the execution of the tests. In summary, 390 tags were requested to meet the needs for all the tests.

Test Results

Table I summarizes the results of all tests. Based on these results, it is concluded that the LabelLase® tags exhibited a strong durability under all test conditions.

The final results of the abrasion test should be interpreted carefully, since the objective was to test the tags to failure. The LabelLase® tags performed very well in this test, considering the fact that they were exposed to very coarse sandpaper while a significant amount of pressure was applied to their surface with the lathe. Symbols used in these tests survived (and were able to be read) even after 15 to 30 seconds of continuous exposure to abrasion.

Table I. Summary of Results for the Durability Tests

	LabeLase® tags	
Test	**Passed**	**Failed**
High Temperature	34	0
Contamination by Fluids:		
Diesel	34	0
Hydraulic Fluid	34	0
Salt Fog	34	0
Icing/Freezing Rain	34	0
Abrasion with sandpaper		
Fine 220 Grit	**29**[1]	**5**
Medium 80 Grit	**21**[1]	**13**
Coarse 40 Grit	**17**[2]	**17**
Impact	34	0
Exposure to Ultraviolet Light	34	0

[1] **Survived three consecutive 15-second abrasion intervals**
[2] **Survived one 15-second abrasion intervals**

Although the results of this battery of durability tests cannot be extrapolated to real-world environmental conditions over long periods of time, laboratory simulations of a variety of conditions provide some degree of evidence that these laser-marked bar code tag technologies may be robust for many military and commercial applications that occur in extreme and diverse weather and climate conditions.

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1.0 INTRODUCTION

Bruno Associates, Inc. expressed an interest in acquiring selected performance data for the following bar code printing technology:

- **Infosight's LabeLase® 1000 tag printer**. The LabeLase® 1000 tag printer is designed to print high quality bar code symbols on standard 300-foot (90-meter) rolls of continuous metallic tag stock, pre-nick and notched for easy break off after printing. Figure 1 depicts a sample tag printed with the LabeLase® 1000 tag printer. These symbols are printed using CO_2 laser technology. The metal tag is covered with a proprietary silicone coating of which is discolored by the CO_2 laser to create both symbology and human readable information.

Figure 1. Sample Tags Printed with the LabeLase® 1000 Tag Printer

Specifically, Bruno Associates was interested in determining whether or not the readability of the symbols printed onto the LabeLase® tags was affected by exposure to a variety of environmental conditions. In response to this need, the Oregon State University (OSU) Mobile Technology Solutions Laboratory performed this evaluation as an independent third party to ensure data objectivity.

1.1 SELECTED TESTS

Four tests were selected from the MIL-STD-810F standard to be carried out on the test LabeLase® sample tags. Three additional tests, not listed in the MIL-STD-810F, were also conducted. These tests are presented in Table 1.

Table 1. Selected Environmental Test Methods

TEST METHODS	
501	High Temperature
504	Contamination by Fluids[1]
509	Salt Fog
521	Icing, Freezing Rain
*	Abrasion[2]
*	Exposure to ultraviolet light
*	Impact

*** Test not included in MIL-STD-810F Standard**
[1] Two different contaminating fluids were used in this test (hydraulic fluid and diesel fuel)
[2] Three different grades of sand paper were used in this test.

1.2 TEST SYMBOLS

The LabeLase® tags were encoded with three bar codes: a Code 39 symbol and two Data Matrix symbols. The X-dimensions of these bar codes were 7 mils, 14 mils, and 17.5 mils, respectively. An example of data encoded onto these symbols was as follows:

- Code 39 bar code
  - 6574867630097865
- 14 mils Data Matrix symbol
  - [)>? 06? 17V00043? S5513HGR131312654? 1P65748676350097
- 17.5 mils Data Matrix symbol
  - [)>? 06? 17V00043? S5513HGR131312654? 1P65748676350097

Figure 2 depicts the layout of the LabeLase® laser-marked tags.

Figure 2. LabeLase® Laser-marked Tags

1.3 BAR CODE READER

A Portable Data Terminal from Symbol Technologies, model PDT 8146-based direct-part marking (DPM) prototype, was employed to scan the Code 39 and Data Matrix bar codes encoded onto the test tags. The PDT 8100 series reader "is a ruggedized handheld computer that features a powerful miniature imaging system with Smart Focus technology for superior image quality and fast, accurate bar code data capture at the point of activity."[1] The PDT 8146-based DPM prototype reader is depicted in Figure 3.

Figure 3. Symbol Technologies' PDT 8146-based DPM Prototype Reader

[1] http://www.symbol.com/products/mobile_computers/mobile_pdt8100_intel_xs.html

1.4 SAMPLE SIZE DETERMINATION

The primary objective behind choosing a sample size for the durability tests was to ensure that it was not falsely concluded that the error rate was less than a particular value (represented by $\mathbf{p_2}$) when in fact it was higher than this value.

However, it is not possible to determine a unique sample size based on this criterion alone. In conformity with the customary statistical practice used in determining sample sizes (i.e., Acceptance Sampling procedures), a second criterion is needed.

When it was concluded based on the results of the tests that the batch of test sample tags under consideration had an ***error rate*** of less than $\mathbf{p_2}$, it was stated that "the batch of test sample tags passed the test." The criteria for choosing the sample size are based on this terminology. The minimum sample size used in the durability tests satisfied the following two probability requirements:

Prob [accept the batch of test sample tags when the true error rate is $\geq p_2$] $\leq \beta$
Prob [reject the batch of test sample tags when the true error rate is $\leq p_1$] $\leq \alpha$

The first inequality states that the sample size should be large enough such that if the or rate is greater than $\mathbf{p_2}$, there is a very small chance (less than β) of not detecting it. On he other hand, if the error rate is definitely quite satisfactory (assumed here to be less than $\mathbf{p_1}$), there is a low probability (less than α) of "rejecting" the batch of test sample tags.

From experience in previous projects in which similar experiments were performed, a typical value for $\mathbf{p_2}$ is 10%. Similarly, $\mathbf{p_1}$ ranges between 1% and 5%, whereas the risk values of α and β are typically set between 5% and 10%. It is important to mention that the use of this standard for comparison does not imply that this is Bruno Associates' final policy determination on the acceptable error rate for the batch of test sample tags.

Table 2 presents the minimum required sample size, ***n***, obtained from reference [1] for different sampling plans. The sampling size can vary and is based on the selected values for $\mathbf{p_1}$, $\mathbf{p_2}$, α and β. These values of ***n*** represent the minimum required sample size to guarantee the two probability requirements given in equations (1) and (2). In addition, the value of ***c*** shown in Table 2 represents the allowable number of observed failures for a particular sampling plan. For example, if sampling plan #1 was used, the batch of test sample tags would have passed the test and the test would have been considered a success if the number of observed failures did not exceed 16. On the other hand, if the number of failures was greater than 16, it would have been considered a failure and the batch of test sample tags would have not passed the test.

[1] Burstein, H,. (1971), Attribute Sampling: Tables and Explanations. McGraw Hill.

Table 2. Minimum Required Sample Size for Different Values of p_1, p_2, α and β

Sampling Plan	p_1	p_2	α	β	c	N
1	0.04	0.10	0.05	0.01	16	274
2	0.04	0.10	0.05	0.05	11	186
3	0.05	0.10	0.05	0.05	20	285
4	0.03	0.10	0.05	0.05	6	117
5	0.02	0.10	0.05	0.05	3	75
6	0.01	0.10	0.05	0.05	1	50
7	0.01	0.10	0.10	0.10	1	34

From reference [1], it was determined that to guarantee the two probability requirements given in equations (1) and (2) with a 90% confidence level, sampling plan #7 with a minimum sample size of n = 34 was needed. For this sampling plan, if the number of observed failures did not exceed 1, then the batch of test sample tags under evaluation was accepted; otherwise it was rejected.

To be able to execute this plan, it was recommended that Bruno Associates provides the OSU team with a sample of the following:

1. Thirty-four (34) LabeLase® metallic tags per durability test, for a total of 340 metallic tags (34 metallic tags * 10 tests = 340 tags).

It was also recommended that Bruno Associates provide the OSU team with 5 additional test samples per test as a backup. In summary, in the process of carrying out the durability tests described in Section 2.0, a total of 390 LabeLase® metallic tags were requested.

2.0 DURABILITY TESTS & RESULTS

2.1 HIGH TEMPERATURE TEST

The objective of this test was to assess the degradation on performance and continued readability of the test sample tags after exposure to high temperature conditions. This test simulated the severe temperature conditions found in regions of the world with hot climates.

2.1.1 Test Equipment

- Temperature chamber (see Figure 4).
- Gages to monitor:
  - Temperature in the chamber.
  - Temperature of the test sample tags.
  - Humidity in the temperature chamber.

Figure 4. Autoclave Air Temperature Cell

2.1.2 Test Procedure

Step 1: Before performing the high-temperature test, conduct a visual examination of the test sample tags to identify any physical defects or damage that may be present and read each individual test sample tag. Record the number of successful and unsuccessful reads and note any observed physical defects or abnormalities. If any of the bar code symbols contained in the tag takes longer than four seconds to read, it will be considered an unsuccessful read.

Step 2: Place the test sample tags inside the temperature chamber at standard ambient conditions. (Temperature = 77°F ± 18°F, Relative humidity = 20 to 80%, Atmospheric pressure = Site pressure)

Step 3: Adjust the chamber's temperature to 91°F (33°C) and maintain that temperature until the test sample tags stabilize at this temperature. The test sample tags are said to be stabilized at the chamber's temperature when its temperature changes at the rate no more than 3.60°F per hour.

Step 4: Expose the test sample tags to the temperature conditions of the storage cycle for at least seven 24-hour cycles. A 24-hour temperature cycle consists of changing the temperature of the test sample tags surroundings from 91°F to 160°F (33°C to 71°C) and back to 91°F (33°C) over a 24-hour period. The rate of temperature change should not exceed 6°F (3°C) per minute to prevent thermal shock.

Step 5: At the completion of the last cycle, adjust the temperature chamber's air temperature to standard ambient conditions and allow the test sample tags' external temperature to stabilize.

Step 6: Conduct a post-test visual examination and read each individual test sample tag. Record the number of successful and unsuccessful reads and note any observed physical defects or abnormalities. If any of the bar code symbols contained in the tag takes longer than four seconds to read, it will be considered an unsuccessful read.

2.1.3 Test Results

The high temperature test was performed using a program controllable oven. In this test, no physical defects were found either in the pre or post-visual inspection. All tags were successfully read before and after the heating process. The results of the high temperature test are summarized in Table 3.

Table 3. High Temperature Test Results

	Tested	Result	
		Passed	Failed
LabeLase® Tags			
Code 39 Bar Code Symbol	34	34	0
Small Data Matrix Symbol	34	34	0
Large Data Matrix Symbol	34	34	0

Based on these results, it can be concluded that LabeLase® Tags passed the high temperature test conforming to the MIL-STD-810F standard.

2.2 CONTAMINATION BY FLUIDS TEST

The objective of the test was to assess the degradation on performance and continued readability of the test sample tags after exposure to contaminating fluids. It was anticipated that the test sample tags may be used as identification tags on heavy equipment, and this test demonstrated the resistance to damage from fluids that are commonly encountered when using many types of equipment. The two contaminating fluids used in this test were:

- **Diesel fuel**
- **Hydraulic fluid**. John Deer's Hy-Gard™ hydraulic/transmission fluid. Hy-Gard oil has a viscosity between the ISO grades of 46 and 68 @ 40°C.

2.2.1 Test Equipment

- Contamination facility
  - Tank within the test enclosure (non-reactive with the contaminant) in which the test sample tags were exposed to the selected contaminant by immersion.
- Thermometer for recording the temperature of the contamination fluid.
- Thermometer for recording the temperature of the test sample tag.

2.2.2 Test Procedure

Step 1: Before performing the contamination by fluids test, conduct a visual examination of the test sample tags to identify any physical defects or damage that may be present and read each individual test sample tag. Record the number of successful and unsuccessful reads and note any observed physical defects or abnormalities. If any of the bar code symbols contained in the tag takes longer than four seconds to read, it will be considered an unsuccessful read.

Step 2: Let the test fluid's temperature stabilize to the ambient temperature.

Step 3: Immerse test sample tags in the specified test fluid for 24 hours. After the 24 hours have elapsed, allow the test sample tags to drain naturally.

Step 4: Expose the test sample tags to ambient temperature conditions for 8 hours. Visually examine the test sample tags for any physical deterioration. Also, perform a read operation on the test sample tags and record the results. If the test sample tags are still operational, repeat this procedure for another 16 hours and perform the visual and read checks again.

Step 5: If the test sample tags are still operational, repeat step 4 for two additional 24-hour periods.

Step 6: Let the test sample tags stabilize at standard ambient conditions.

Step 7: Conduct a post-test visual examination and read each individual test sample tag. Record the number of successful and unsuccessful reads and note any observed physical defects or abnormalities. If any of the bar code symbols contained in the tag takes longer than four seconds to read, it will be considered an unsuccessful read.

2.2.3 Test Results

2.2.3.1 Fuels Fluid Group -- Diesel

In this test, no physical defects were found on the LabeLase® tags in either the pre-test or post-test visual examination. Also, all the pre-test and after-test reads were performed successfully for all tags. The results of this test are summarized in Table 4.

Based on these results, it can be concluded that LabeLase® tags passed the Contamination by Fluids (Diesel) test conforming to the MIL-STD-810F standard.

Table 4.Contamination by Fluids (Diesel) Test Results

	Tested	Result	
		Passed	Failed
LabeLase® Tags			
Code 39 Bar Code Symbol	34	34	0
Small Data Matrix Symbol	34	34	0
Large Data Matrix Symbol	34	34	0

2.2.3.2 Hydraulic Oils Group – Mineral Based

In this test, no physical defects were found on the LabeLase® tags in either the pre-test or post-test visual examination. Also, the pre-test and after-test reads were performed successfully for all tags. The results of this test are summarized in Table 5.

Based on these results, it can be concluded that LabeLase® tags passed the Contamination by Fluids (Hydraulic oil) test conforming to the MIL-STD-810F standard.

Table 5. Contamination by Fluids (Hydraulic Oil) Test Results

	Tested	Result	
		Passed	Failed
LabeLase® Tags			
Code 39 Bar Code Symbol	34	34	0
Small Data Matrix Symbol	34	34	0
Large Data Matrix Symbol	34	34	0

2.3 SALT FOG TEST

The objective of this test was to assess the degradation on performance and continued readability of the test sample tags after their exposure to periods of Salt Fog. This test was designed to simulate those regions of the world that are in proximity to a marine environment where exposure to salt in the atmosphere is likely.

2.3.1 Test Equipment

- Salt fog test chamber.
  - Supporting racks did not affect the characteristics of the salt fog mist.
  - Condensation was controlled and prevented from dripping directly on the test sample tags.
  - The salt solution was not returned to the supplying reservoir preventing contamination from the test chamber or test sample tags surface.
  - The test chamber was vented to prevent pressure buildup.

2.3.2 Test Procedure

Step 1: Before performing the salt fog test, conduct a visual examination of the test sample tags to identify any physical defects or damage that may be present and read each individual test sample tag. Record the number of successful and unsuccessful reads and note any observed physical defects or abnormalities. If any of the bar code symbols contained in the tag takes longer than four seconds to read, it will be considered an unsuccessful read.

Step 2: Adjust the salt fog test chamber's temperature to 95°F (35°C) and expose the test sample tags to this temperature for at least two hours before introducing the salt fog.

Step 3: Continuously atomize a 5 ± 1% salt solution into the salt fog test chamber for a period of 24 hours. During the entire exposure period measure the salt fog fallout rate and pH of the fallout solution at 24-hour intervals. Ensure the fallout is between 1 and 3 $ml/80cm^2/hr$.

Step 4: Let the test sample tags dry at standard ambient temperature and at a relative humidity of 50% or less for 24 hours. Do not disturb the test sample tags or adjust any mechanical features during the drying period.

Step 5: At the end of the drying period the test sample tags will be returned to the salt fog chamber and steps 2 and 3 will be repeated one more time to get a total two wet and two dry 24-hour periods.

Step 6: Conduct a post-test visual examination of the test sample tags and document the results. If necessary, use a gentle wash in running water (at standard ambient conditions) to aid in the corrosion examination.

Step 7: Conduct a post-test visual examination and read each individual test sample tag. Record the number of successful and unsuccessful reads and note any observed physical defects or abnormalities. If any of the bar code symbols contained in the tag takes longer than four seconds to read, it will be considered an unsuccessful read.

2.3.3 Test Results

The salt fog test was performed using a test chamber created for this purpose. This chamber is depicted in Figure 5.

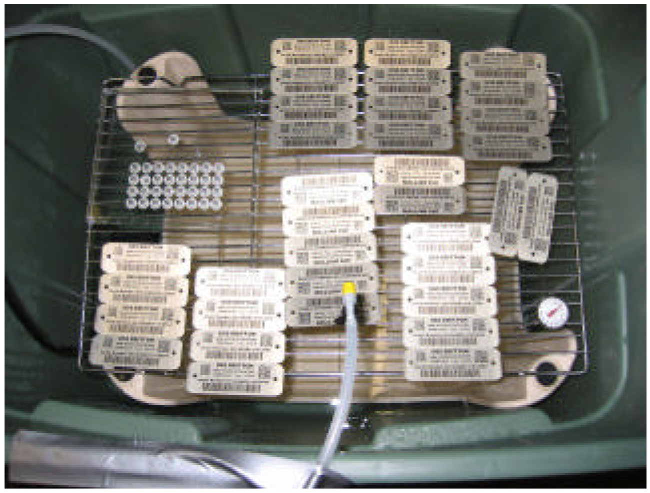

Figure 5. Salt Fog Chamber

To approximate the actual salinity of seawater, the saline solution used in the test was created using Instant Ocean® with a specific gravity adjusted to 1.023. The saline mix also included macro and micronutrients typically found in seawater (e.g., chloride, sodium, sulfate, and potassium, etc.). The temperature of the chamber's water supply was maintained at 95°F (35°C).

In this test, no physical defects were found on the LabeLase® tags in either the pre or post-visual inspection. Also, all LabeLase® tags were successfully read before and after the exposure to the salt fog. The results of the salt fog test are summarized in Table 6.

Table 6. Salt Fog Test Results

	Tested	Result	
		Passed	Failed
LabeLase® Tags			
Code 39 Bar Code Symbol	34	34	0
Small Data Matrix Symbol	34	34	0
Large Data Matrix Symbol	34	34	0

Based on these results, it can be concluded that LabeLase® tags passed the salt fog test.

2.4 ABRASION TEST

The objective of this test was to assess the degradation on performance and continued readability of the test sample tags after exposure to abrasion. This test was performed to simulate abrasion that might occur due to the following conditions:

1. Exposure of the tag's surface to contact with foreign objects, such as during shipment.
2. Incidental contact with sanders used on and around tools and shelves.

2.4.1 Test Equipment

- Abrasive materials
  - Three grit sizes of CAMI Grade sand paper of aluminum oxide
    - Very coarse #40
    - Medium #80
    - Very fine #220
- Lathe (see Figure 6)

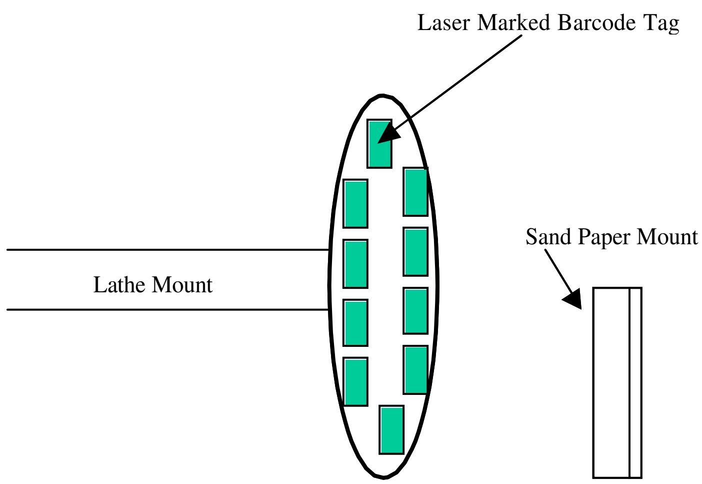

Figure 6. Side View of Abrasion Station

2.4.2 Test Procedures

Step 1: Before performing the abrasion test, conduct a visual examination of the test sample tags to identify any physical defects or damage that may be present and read each individual test sample tag. Record the number of successful and unsuccessful reads and note any observed physical defects or abnormalities. If any of the bar code symbols contained in the tag takes longer than four seconds to read, it will be considered an unsuccessful read.

Step 2: Attach the test sample tags on the grinding mount of the lathe.

Step 3: Attach the sandpaper to the grinding surface.

Step 4: Set the rpm of the lathe to 35 rpm.

Step 5: Expose the test sample tags to the grinding process for 15 seconds.

Step 6: Conduct a post-test visual examination of the test sample tags and document the results. If necessary, use a gentle wash in running water (at standard ambient conditions) to aid in the visual examination of the abrasive process. Dry the test sample tags thoroughly.

Step 7: Conduct a post-test visual examination and read each individual test sample tag. Record the number of successful and unsuccessful reads and note any observed physical defects or abnormalities. If any of the bar code symbols contained in the tag takes longer than four seconds to read, it will be considered an unsuccessful read.

Step 8: Repeat the steps 1 through 7 for ten 15-second intervals or until failure, which ever occurs first.

Step 9: Repeat steps 1 through 8 for each grade of sandpaper.

2.4.3 Test Results

The abrasion test was performed using a fixture built specifically for the task. This fixture is depicted in Figure 7 and Figure 8.

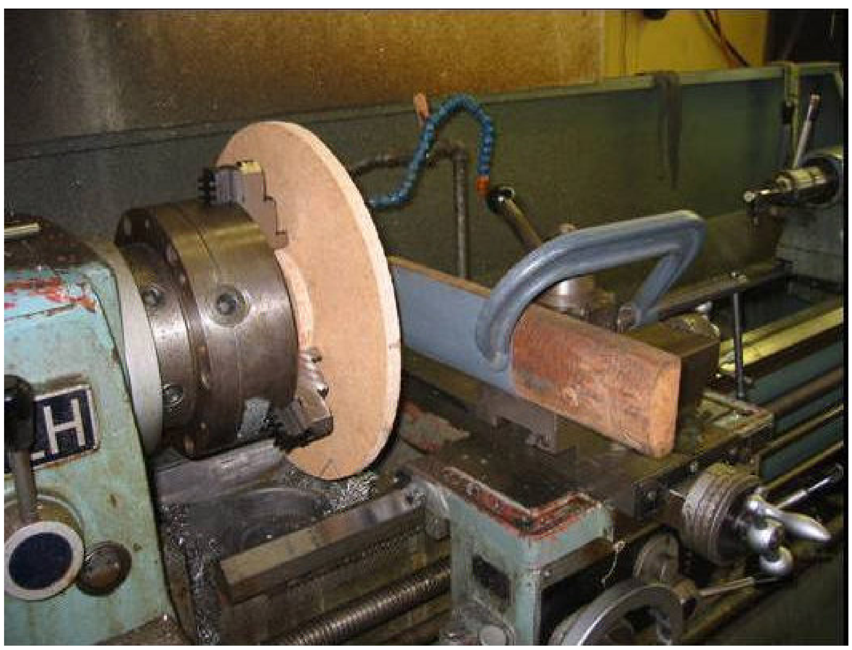

Figure 7. Abrasion Station (Back View)

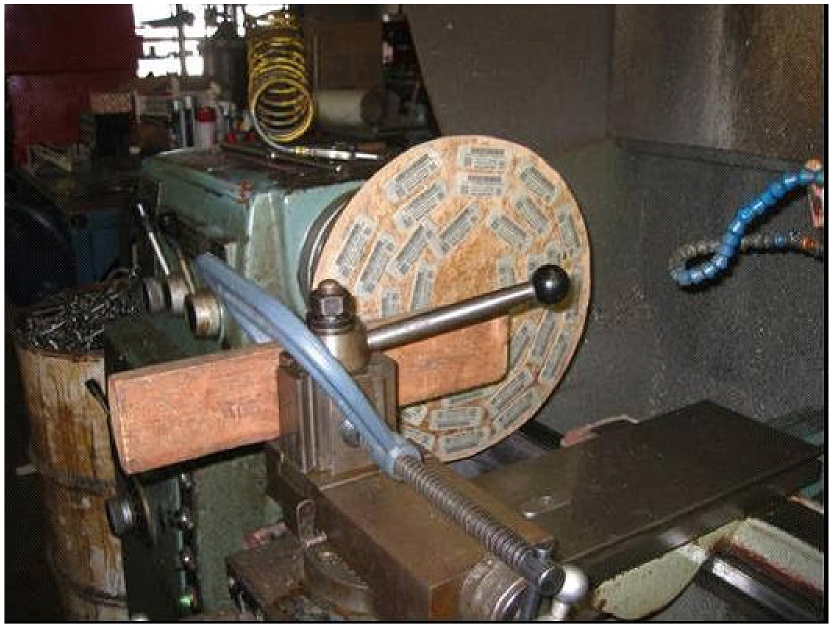

Figure 8. Abrasion Station (Front View)

In this test, no physical defects were found on the LabeLase® tags in the pre-visual inspection. All tags were successfully read before the abrasion process. The fixture that held the test samples was advanced until there was an audible sound from the contact with the sandpaper. The timer was started at the first sound of contact and the fixture was advanced an additional 10/1000 of an inch.

The results obtained in the abrasion test with the fine sand paper (i.e., 220 grit) are shown in Table 7. The LabeLase® tags withstood three consecutive 15-second cycles of abrasion, failing in the fourth 15-second interval.

Table 7. Abrasion Test Results -- 220 Grit Sand Paper (Fine)

	Tested	Run 1 15-Seconds Result		Run 2 15-Seconds Result		Run 3 15-Seconds Result		Run 4 15-Seconds Result	
		Passed	Failed	Passed	Failed	Passed	Failed	Passed	Failed
LabeLase® Tags									
Code 39 Bar Code Symbol	34	34	0	34	0	34	0	29	5
Small Data Matrix Symbol	34	34	0	34	0	34	0	32	2
Large Data Matrix Symbol	34	34	0	34	0	34	0	32	2

The results obtained in the abrasion test with the medium sand paper (i.e., 80 grit) are shown in Table 8. The LabeLase® tags withstood three consecutive 15-second cycles of abrasion, failing in the fourth 15-second interval.

Table 8. Abrasion Test 80 Grit Sand Paper (Medium)

	Tested	Run 1 15-Seconds Result		Run 2 15-Seconds Result		Run 3 15-Seconds Result		Run 4 15-Seconds Result	
		Passed	Failed	Passed	Failed	Passed	Failed	Passed	Failed
LabeLase® Tags									
Code 39 Bar Code Symbol	*34*	*34*	*0*	*34*	*0*	*34*	*0*	***21***	***13***
Small Data Matrix Symbol	*34*	*34*	*0*	*34*	*0*	*34*	*0*	***29***	***5***
Large Data Matrix Symbol	*34*	*34*	*0*	*34*	*0*	*34*	*0*	***25***	***9***

The results obtained in the abrasion test with the coarse sand paper (i.e., 40 grit) are shown in Table 9. The LabeLase® tags withstood the first 15-second cycle of abrasion, failing in the second interval.

Table 9. Abrasion Test 40 Grit Sand Paper (Coarse)

	Tested	Run 1 15-Seconds Result		Run 2 15-Seconds Result	
		Passed	Failed	Passed	Failed
LabeLase® Tags					
Code 39 Bar Code Symbol	*34*	*34*	*0*	***17***	***17***
Small Data Matrix Symbol	*34*	*34*	*0*	***13***	***13***
Large Data Matrix Symbol	*34*	*34*	*0*	***9***	***9***

Figure 9 depicts some of the damage incurred by the tags during the abrasion tests.

Figure 9. View of LabelLase® Damage after an Abrasion Run

2.5 ICING/FREEZING RAIN

The objective of this test was to assess the degradation on performance and continued readability on the test sample tags after being subjected to freezing rain and ice accumulation. This test was designed to simulate icing conditions that could be encountered in some parts of the world and in aviation.

2.5.1 Test Equipment

- Freezing rain icing accumulation test chamber.
  - Supporting racks did not affect the characteristics of the water mist deposition.
  - Condensation was controlled and prevented from dripping directly on the test sample tags.
  - The solution was not returned to the supplying reservoir preventing contamination from the test chamber or test sample tags surface.
  - The test chamber was vented to prevent pressure buildup.
- Cold water delivery system
- Temperature measuring devices to measure the chamber temperature
- Depth gauge

2.5.2 Test Procedure

Step 1: Before performing the Icing/Freezing Rain test, conduct a visual examination of the test sample tags to identify any physical defects or damage that may be present and read each individual test sample tag. Record the number of successful and unsuccessful reads and note any observed physical defects or abnormalities. If any of the bar code symbols contained in the tag takes longer than four seconds to read, it will be considered an unsuccessful read.

Step 2: Adjust the Icing/Freezing Rain test chamber's temperature to 14°F (-10°C) and expose the test sample tags to this temperature for at least two hours before introducing the Icing/Freezing Rain solution.

Step 3: Position depth gage measuring devices so that the thickness can be easily measured prior to testing.

Step 4: Cool the water supply to between 32°F (0°C) and 41°F (5°C). Deliver the water atomized spray into the Icing/Freezing Rain test chamber at a rate of 25 mm/h. The droplet size of the water sprayed on top of the test sample tags should be between 1mm and 1.5mm.

Step 5: When an application thickness of 6mm has been achieved on the surface of the test sample tags, the application will be halted and the test chamber temperature will be maintained for four hours to allow the ice to harden.

Step 6: At the end of the hardening period, an attempt to read the test sample tags without removing the ice will be conducted and the results recorded. If the test sample tags can be read successfully without ice removal, then repeat steps one through 5 to continue the application process and increase the thickness of the ice to the next desired thickness level. Repeat this process for all four different thicknesses (6mm, 13mm, 37mm, and 75mm).

Step 7: After steps 1 through 6 have been repeated as required, the ice will be removed by striking the flat surface with a hammer to fracture the ice and facilitate removal.

Step 8: Conduct a post-test visual examination and read each individual test sample tag. Record the number of successful and unsuccessful reads and note any observed physical defects or abnormalities. If any of the bar code symbols contained in the tag takes longer than four seconds to read, it will be considered an unsuccessful read.

2.5.3 Test Results

The icing/freezing rain test was performed using a freezer with the temperature set at 14°F (-10°C). The water was introduced over the top of the freezer and the solution was frozen to form a clear ice coating that covered the tags to a uniform depth of 6mm. After the prescribed hardening period, the tags were removed from the freezer and the ice was removed. All tags were visually inspected and read. This process was repeated for all four recommended ice thicknesses.

No physical defects were found on the LabeLase® tags in either the pre or post-visual inspection in all test cases. All tags were successfully read before and after the icing/freezing process. The results of the icing/freezing rain test are summarized in Table 10.

Table 10. Icing/Freezing Rain Test Results

	Tested	Result	
		Passed	Failed
LabeLase® Tags			
Code 39 Bar Code Symbol	*34*	*34*	*0*
Small Data Matrix Symbol	*34*	*34*	*0*
Large Data Matrix Symbol	*34*	*34*	*0*

Based on these results, it can be concluded that LabeLase® tags passed the Icing/freezing rain test.

2.6 IMPACT TEST

The objective of this test was to assess degradation on performance and continued readability of the test sample tags after a direct impact of measured force. This test simulated the results of an impact that could result from an object accidentally being dropped on, or falling against, the surface where the test sample tags are mounted on.

2.6.1 Test Equipment

- Impact test station (see Figure)
- Impact force generator

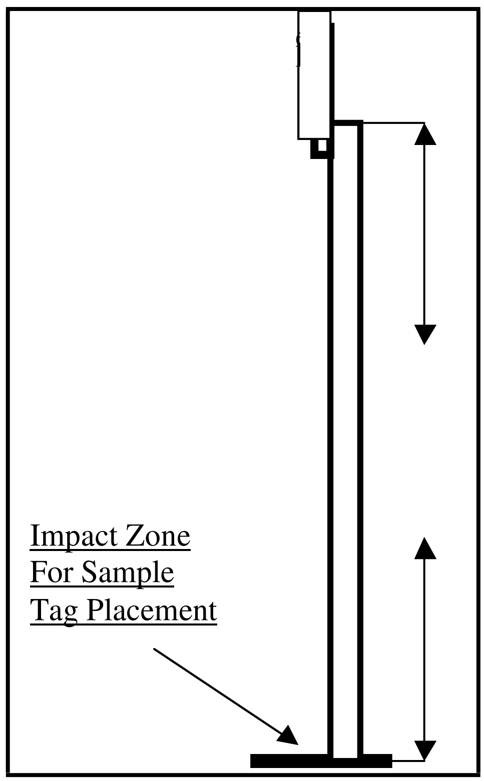

Figure 10. Impact Test Station

2.6.2 Test Procedures

Step 1: Before performing the impact test, conduct a visual examination of the test sample tags to identify any physical defects or damage that may be present and read each individual test sample tag. Record the number of successful and unsuccessful reads and note any observed physical defects or abnormalities. If any of the bar code symbols contained in the tag takes longer than four seconds to read, it will be considered an unsuccessful read.

Step 2: Install the test sample tags on the test station.

Step 3: Drop a 2-lb impact load from a test height of 48 inches onto the test sample tags, with the test sample tags being positioned so that the blow will strike the surface at a 45-degree angle to the label.

Step 4: Conduct a post-test visual examination and read each individual test sample tag. Record the number of successful and unsuccessful reads and note any observed physical defects or abnormalities. If any of the bar code symbols contained in the tag takes longer than four seconds to read, it will be considered an unsuccessful read.

Step 5: Repeat step 3 with a 5-lb impact load, then perform step 4.

Step 6: Repeat step 3 with a 10-lb impact load, then perform step 4.

2.6.3 Test results

The impact fixture was built specifically for this test. The impact station was designed with a piece of 0.25 inch diameter steel rod attached to the bottom of the impact-sled. The tags were placed in the impact zone; the weight was attached to the sled and the sled was dropped from the prescribed height onto the tag, impacting the surface of the tag. The impact fixture is depicted in Figure 11 and Figure 12.

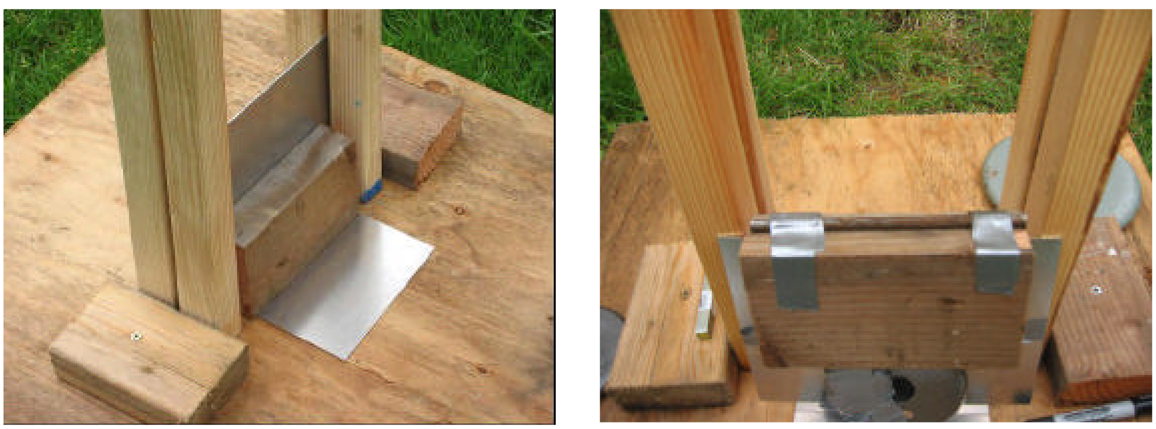

Figure 11. Impact Station and Impact Sled

Figure 12. Impact station

All LabeLase® tags passed the visual pre-inspection and were readable after the test was completed. This procedure was repeated with each successively heavier weight. All LabeLase® tags continued to perform and were readable even after the cumulative damage of all three impacts. The results are presented in Table 11. Figure 13 shows some of the damage incurred from the test procedure.

Table 11. Impact Test Results

	Tested	Run 1 2 lbs		Run 2 5 lbs		Run 3 10 lbs	
		Passed	Failed	Passed	Failed	Passed	Failed
LabeLase® Tags							
Code 39 Bar Code Symbol	*34*	*34*	*0*	*34*	*0*	*34*	*0*
Small Data Matrix Symbol	*34*	*34*	*0*	*34*	*0*	*34*	*0*
Large Data Matrix Symbol	*34*	*34*	*0*	*34*	*0*	*34*	*0*

Figure 13. Impact damage to tags after impact from three weights

Based on these results, it can be concluded that LabeLase® tags passed the impact test.

2.7 EXPOSURE TO ULTRAVIOLET LIGHT TEST

The objective of this test was to assess the degradation on performance and continued readability of the test sample tags after simulated long-term exposure to sunlight. In this test, sunlight was simulated using an ultraviolet (UV) light source that reproduces that portion of the electromagnetic spectrum that ranges from 200 – 400nm.

2.7.1 Test Equipment

- Ultraviolet light source (see Figure 14).
  - Palm Springs Sunlamp
  - Manufactured by KBI Inc.
  - 700 watts of power
  - 70 % UVB
  - 30 % UVA

Figure 14. KBI's Ultraviolet Light Source

- Enclosed test station
- Measurement device to monitor the amount of UV light hitting the test sample tags during the test.

2.7.2 Test Procedures

Step 1: Before performing the ultraviolet light exposure test, conduct a visual examination of the test sample tags to identify any physical defects or damage that may be present and read each individual test sample tag. Record the number of successful and unsuccessful reads and note any observed physical defects or abnormalities. If any of the bar code symbols contained in the tag takes longer than four seconds to read, it will be considered an unsuccessful read.

Step 2: Install the test sample tags in the test station.

Step 3: Turn on the UV light source and measure the amount of light that is being generated by the lamp in the enclosed test station. Record the results.

Step 4: Expose the test sample tags to the UV light for 24 hours. This was completed in four 6 hour intervals to minimize the potential for fire that could occur through the heat generated by the UV Light (approximately 200 degrees F).

Step 5: At the end of the test session, measure and record the amount of UV light that the lamp is generating inside the box and record the results.

Step 6: Conduct a post-test visual examination and read each individual test sample tag. Record the number of successful and unsuccessful reads and note any observed physical defects or abnormalities. If any of the bar code symbols contained in the tag takes longer than four seconds to read, it will be considered an unsuccessful read.

2.7.3 Test Results

The ultraviolet light test was performed using a 700-watt UV lamp that produces 65% of its light in the UVA range (320-400 nanometers), and 35% of its light in the UVB range (280-320 nanometers). The LabeLase® tags were placed 15 inches away from the light source well within the footprint of the light. In this test, no physical defects were found on the LabeLase® in either the pre or post-visual inspection. All tags were successfully read before and after exposure to the ultraviolet light source. The results of the ultraviolet light test are summarized in Table 12.

Table 12. Ultraviolet Light Test Results

	Tested	Result	
		Passed	Failed
LabeLase® Tags			
Code 39 Bar Code Symbol	34	34	0
Small Data Matrix Symbol	34	34	0
Large Data Matrix Symbol	34	34	0

Based on these results, it can be concluded that LabeLase® tags passed the ultraviolet light exposure test.

3.0 CONCLUSIONS

Table 13 summarizes the results of all tests. Based on these results, it is concluded that the LabelLase® tags exhibited a strong durability.

The final results of the abrasion test should be interpreted carefully, since the objective was to test the tags to failure. The LabelLase® tags performed very well in this test, considering the fact that they were exposed to very coarse sandpaper while a significant amount of pressure applied to their surface with the lathe.

Table 13. Summary of Test Results

	LabeLase® tags	
Test	**Passed**	**Failed**
High Temperature	34	0
Contamination by Fluids:		
Diesel	34	0
Hydraulic Fluid	34	0
Salt Fog	34	0
Icing/Freezing Rain	34	0
Abrasion with sandpaper		
Fine 220 Grit	**29**[1]	**5**
Medium 80 Grit	**21**[1]	**13**
Coarse 40 Grit	**17**[2]	**17**
Impact	34	0
Exposure to Ultraviolet Light	34	0

[1] **Survived three consecutive 15-second abrasion intervals**
[2] **Survived one 15-second abrasion intervals**

Although the results of this battery of durability tests cannot be extrapolated to exposure to real-world environmental conditions over long periods of time, laboratory simulations of a variety of conditions provide some degree of evidence that the laser-marked bar code tag technology evaluated in this study may be robust for many military and commercial applications that occur in extreme and diverse weather and climate conditions.

In summary, the project team was highly impressed with the performance and durability of the LabelLase® tags. On a special note, the laser ablation printer that produced the LabelLase® tags is, in our opinion, a major breakthrough in technology for durable part marking. A laser ablation marking system can cost upwards of over $400,000. The LabelLase product currently retails for approximately [redacted], and does an excellent job of making high quality durable symbology and human readable marks on the chemically treated metal tags. We believe this product has a bright future in commercial and military applications where the marks must survive very harsh processing and environmental conditions.