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PROGRAM (DESP)**

**Delivery Order RZ16: Effects On Mechanical Properties From  
Laser Paint Stripping**

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## TABLE OF CONTENTS

| SECTION           |   | PAGE |
|-------------------|---|------|
| 1                 | Introduction .....                                      | 1    |
| 2                 | Background.....   | 1    |
| 3                 | Literature Survey and Data Comparison .....             | 1    |
| 4                 | Statistical Analysis .....                              | 2    |
| 5                 | Metallic Literature Search Results .....                | 2    |
|                   | 5.1 Tensile Results .....                               | 2    |
|                   | 5.1.1 2024-T3 Bare .....                                | 4    |
|                   | 5.1.2 2024-T3 Clad .....                                | 4    |
|                   | 5.1.3 7075-T6 Bare .....                                | 5    |
|                   | 5.1.4 7075-T6 Clad .....                                | 5    |
|                   | 5.1.5 Summary .....                                     | 5    |
|                   | 5.2 Fatigue Results.....                                | 6    |
|                   | 5.2.1 2024-T3 Clad Smooth Fatigue.....                  | 7    |
|                   | 5.2.2 2024-T3 Clad Notch Fatigue.....                   | 8    |
|                   | 5.2.3 7075-T6 Bare Smooth Fatigue.....                  | 8    |
|                   | 5.2.4 7075-T6 Bare Notch Fatigue.....                   | 8    |
|                   | 5.2.5 7075-T6 Clad Smooth Fatigue.....                  | 8    |
|                   | 5.2.6 7075-T6 Clad Notch Fatigue.....                   | 8    |
|                   | 5.2.7 Summary .....                                     | 8    |
|                   | 5.3 Fatigue Crack Growth Rate (FCGR) Testing.....       | 9    |
|                   | 5.3.1 FCGR Statistical Analysis .....                   | 12   |
|                   | 5.3.2 FCGR Data Analysis Using ASTM E647.....           | 12   |
|                   | 5.4 Superficial Hardness .....                          | 15   |
|                   | 5.5 Conclusions/Observations.....                       | 16   |
| 6                 | Composite Literature Search Results .....               | 18   |
|                   | 6.1 Four-Point Flexural Testing.....                    | 18   |
|                   | 6.2 Summary .....                                       | 19   |
| 7                 | References .....  | 21   |
| <b>APPENDICES</b> |   |      |
| A                 | Laser Paint Stripping Reference Literature Summary..... | A-1  |
| B                 | Tensile Results.....                                    | B-1  |
| C                 | Fatigue Results .....                                   | C-1  |
| D                 | Fatigue Crack Growth Rate Results .....                 | D-1  |
| E                 | Flexural Strength Results.....                          | E-1  |

## LIST OF FIGURES

| FIGURE |   | PAGE |
|--------|---|------|
| 1      | 2024-T3 Bare Average Tensile Ultimate Strength .....                                      | 3    |
| 2      | 2024-T3 Bare Average Tensile Yield Strength .....   | 3    |
| 3      | 2024-T3 Bare Average Elongation .....   | 4    |
| 4      | 2024-T3 Clad S-N Smooth Fatigue Results.....  | 7    |
| 5      | 2024-T3 Clad S-N Notch Fatigue Results .....  | 7    |
| 6      | Example Plot of FCGR Data .....   | 10   |
| 7      | 7075-T6 Clad Fatigue Crack Growth Rate Test Results .....                                 | 11   |
| 8      | Statistical Representation of FCGR Data for 7075-T6 Clad .....                            | 14   |
| 9      | 7075-T6 Clad Superficial Hardness Results .....   | 15   |
| 10     | 2024-T3 Superficial Hardness Results.....   | 16   |
| 11     | Graphite/Epoxy Flexural Strength Results .....  | 19   |
| B1     | PLCRS and Reference Data Metallic Al 2024-T3 Clad Ultimate Tensile Strength Results ..... | B-2  |
| B2     | PLCRS and Reference Data Metallic Al 2024-T3 Clad Yield Tensile Strength Results .....    | B-3  |
| B3     | PLCRS and Reference Data Metallic Al 2024-T3 Clad Elongation Results .....                | B-4  |
| B4     | PLCRS and Reference Data Metallic Al 7075-T6 Bare Ultimate Tensile Strength Results ..... | B-5  |
| B5     | PLCRS and Reference Data Metallic Al 7075-T6 Bare Yield Tensile Strength Results .....    | B-6  |
| B6     | PLCRS and Reference Data Metallic Al 7075-T6 Bare Elongation Results .....                | B-7  |
| B7     | PLCRS and Reference Data Metallic Al 7075-T6 Clad Ultimate Tensile Strength Results ..... | B-8  |
| B8     | PLCRS and Reference Data Metallic Al 7075-T6 Clad Yield Tensile Strength Results .....    | B-9  |
| B9     | PLCRS and Reference Data Metallic Al 7075-T6 Clad Elongation Results .....                | B-10 |

## LIST OF FIGURES (Continued)

| <b>FIGURE</b> |   | <b>PAGE</b> |
|---------------|---|-------------|
| C1            | PLCRS and Reference Data 7075-T6 Bare Smooth Fatigue Results.....                                       | C-2         |
| C2            | PLCRS and Reference Data Metallic Al 7075-T6 Bare Notch Fatigue Results.....                            | C-3         |
| C3            | PLCRS and Reference Data Metallic Al 7075-T6 Clad Smooth Fatigue Results.....                           | C-4         |
| C4            | PLCRS and Reference Data Metallic Al 7075-T6 Clad Notch Fatigue Results.....                            | C-5         |
| D1            | PLCRS Fatigue Crack Growth Rate Metallic Al 7075-T6 Clad Results.....                                   | D-2         |
| D2            | Metallic Al 7075-T6 Clad Fatigue Crack Growth Rate Statistical Analysis at $\Delta K$ of 6 and 14 ..... | D-3         |
| D3            | PLCRS Fatigue Crack Growth Rate Metallic Al 7075-T6 Bare Results.....                                   | D-4         |
| D2            | Metallic Al 7075-T6 Bare Fatigue Crack Growth Rate Statistical Analysis at $\Delta K$ of 6 and 14 ..... | D-5         |
| E1            | PLCRS Flexural Strength Results.....  | E-2         |
| E2            | PLCRS and Reference Data Flexural Strength Results .....  | E-3         |

## LIST OF TABLES

| <b>TABLE</b> |   | <b>PAGE</b> |
|--------------|---|-------------|
| 1            | Tensile Properties for Various Paint Stripping Methods .....                  | 6           |
| 2            | Fatigue Properties .....  | 9           |
| 3            | Statistical Analysis of Fatigue Crack Growth Rate Data Results for PLCRS..... | 13          |
| 4            | Statistical Analysis of Hardness.....   | 15          |
| 5            | Metallic Matrix for Paint Removal Methods.....                                | 17          |
| 6            | Matrix for Composite Flexural Data.....                                       | 20          |

## **1. INTRODUCTION**

This project, funded under Contract No F42620-00-D-0039, Delivery Order RZ16, evaluated the Portable Laser Coating Removal System (PLCRS) mechanical property tests results compared to the published data of other coating removal systems used by the Department of Defense (DoD). This document was submitted to the Air Force Research Laboratory Materials Laboratory (AFRL/ML). The technical points of contacts at AFRL/MLSC were Mr. Randall Straw and Mr. Thomas Naguy. The Principal Investigators at the University of Dayton Research Institute were Mr. James Coleman and Dr. Peter Sjöblom.

## **2. BACKGROUND**

The processes used to remove coatings from DoD equipment vary from chemical, mechanical, and high intensity light stripping, to hand sanding and scraping. The substrates primarily used on DoD equipment are metallic and composite materials. The Environmental Protection Agency (EPA) requires that the use of hazardous chemicals and materials is held to a minimum. This requirement limits the chemical and mechanical coating removal methods that can release volatile organic compounds (VOCs) and hazardous air pollutants (HAPs) and can produce hazardous waste. The DoD is searching for an environmentally friendly paint removal method to satisfy the environment requirements without decreasing the performance of the substrate material.

## **3. LITERATURE SURVEY AND DATA COMPARISON**

A literature search of 74 published references was conducted on methods commonly used to remove paint from metallic and non-metallic substrates. The references were categorized by substrate and mechanical property data presented. Metallic substrate mechanical properties retrieved from the references were tensile, fatigue, and hardness. No fatigue crack growth data was found in the literature survey. Therefore, no comparison to the data generated in the Portable Laser Coating Removal System (PLCRS) program could be made. The nonmetallic substrate mechanical property commonly found in the literature was flexure strength. The paint removal methods examined were flash lamp, plastic media blasting (PMB), dry media blasting (DMB), chemical, and lasers. A catalog was created to assist in categorizing the large number of references (Appendix A).

The data gathered were compared to the test results from the (PLCRS) program. Statistical analysis was performed on the test results from the PLCRS program and compared to the literature search data gathered using the same statistical analysis approach when possible. The statistical analysis criterion was established by the Engineering and Technical Services for Joint Group on Pollution Prevention Projects Joint Test Protocol J-00-CR-017 (JTP). The JTP is designed to set the standard for acceptable mechanical tests results used to qualify materials for use in the field.

The paint-removed test results were compared to the baseline test results. The evaluation process consisted of a statistical analysis of the baseline test results compared to the paint-removed test results in each reference, where sufficiently detailed data were available, as well as from the PLCRS project.

#### **4. STATISTICAL ANALYSIS**

Statistical analysis was performed on the selected JTP test data. Confidence intervals were constructed at a 90% confidence level for the difference between baselines and de-paint treated specimens. The analyses produces an estimate of the difference between the baseline mean value and the de-paint method mean using calculated confidence intervals (CI) of 90%. A statistical significance is present if the 90% CI is completely positive or negative. A 90% CI straddled across zero represents no statistical significance.

The 90% CI calculations were completed using the (SAS) software package. This software is a widely accepted statistical software package used by statisticians. A reference to the exact methodology used can be found on page 941 of SAS/STAT Users Guide Volume 2, GLM-VARCOMP Version 6 Fourth Edition.

#### **5. METALLIC LITERATURE SEARCH RESULTS**

The primary focus of the metallic substrate literature search was on paint removal testing conducted on aluminum substrates used by the DoD. The JTP requires that four paint removal cycles be performed on the substrate before any mechanical test data is generated. Aluminum 2024-T3 (clad, bare) and 7075-T6 (clad, bare) were the materials selected for the PLCRS project so the data reference search was concentrated on those materials.

##### **5.1 Tensile Results**

The PLCRS and reference data tension results are displayed in Fig. 1. Each baseline and paint removal method was evaluated using at least ten replicates. The average tensile ultimate strength (TUS), tensile yield strength (TYS), and elongation (e) are represented in the graphs. The baseline data for the PLCRS and the reference data are the first bar, plotted in black, in each data set. The bars right of the baseline are the test results after paint removal. Each bar is labeled with the removal method used. The reference from which the data was collected is displayed over the plot.

A statistically significant difference between the baseline and after paint removal is indicated by a '√' mark. A data set without a '√' mark indicates no statistical significance between the baseline and after the paint removal. The Metallic Materials Properties Development and Standardization (MMPDS) Handbook 'A' allowable level is also indicated on the charts, where applicable. Although, one cannot directly compare an A design allowable, statistically derived from 300 test results from 10 different lots, to a

mean of a handful of tests, the A allowable for the material form used is plotted in the graphs to give an indication of the relative strength level of the stripped panels.

The A1 2024-T3 bare material tension results are displayed in Figures 1, 2, and 3. The tension results (plots) for the remaining materials are located in Appendix B.

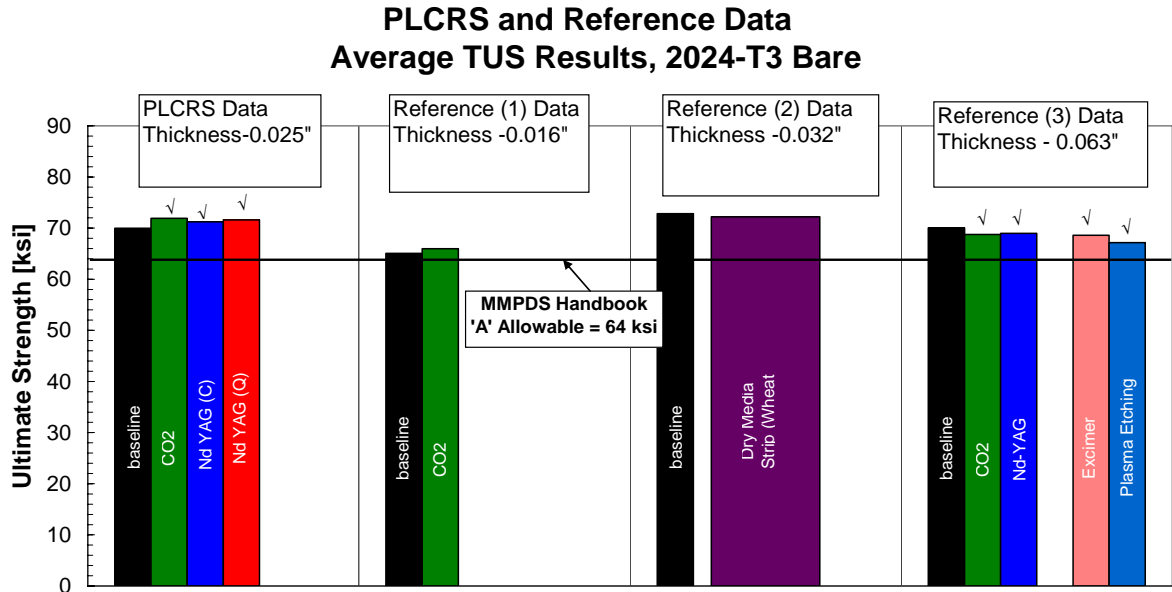


Figure 1. 2024-T3 Bare Average TUS.

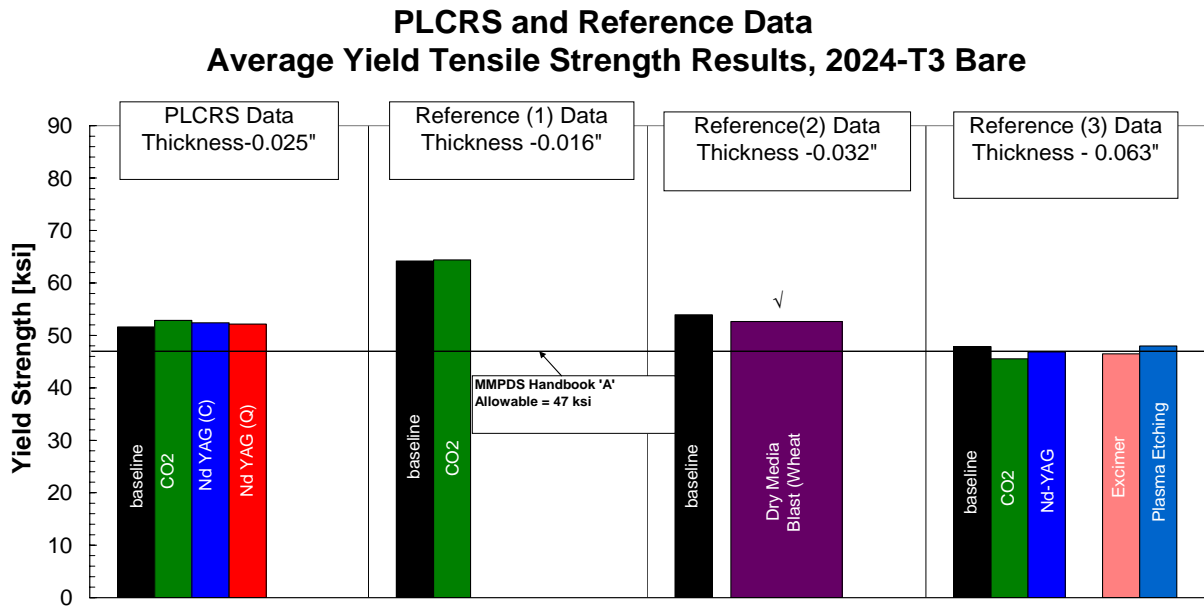
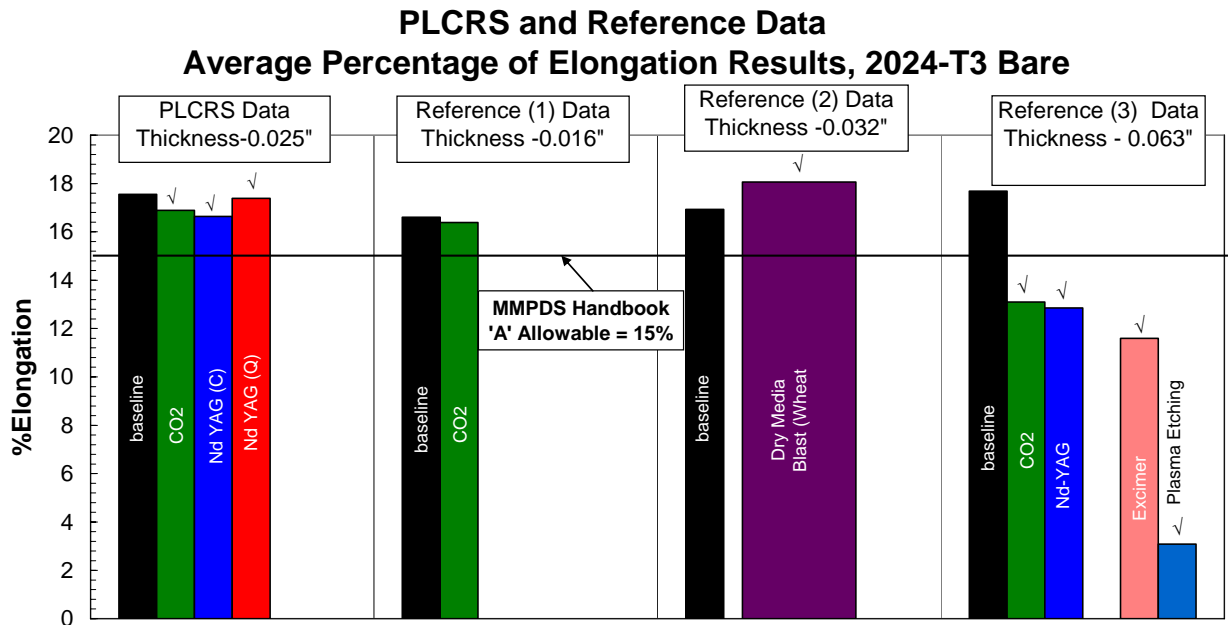


Figure 2. 2024-T3 Bare Average TYS.



**Figure 3. 2024-T3 Bare Average Elongation.**

### 5.1.1 2024-T3 Bare

The paint removal method used in reference (2) was a dry media blast (DMB) while reference (1) and (3) use different lasers for removing paint from the substrate.

Strength: The PLCRS tensile properties for Al 2024-T3 bare show a statistically significant increase in ultimate strength compared to the baseline. The same trend can not be found in the reference data. The reference data either depicts a statistically significant decrease, as in reference (3), or no difference as in reference (1) and (2). Reference (2) has a statistical decrease in yield strength.

Percentage of Elongation: The percentage of elongation data from the PLCRS and reference (3) displays a statistically significant decrease when compared to the baselines used in their respective testing. There was no statistical significance difference for the elongation in the reference (1) results. Reference (2) shows a statistical increase in elongation.

### 5.1.2 2024-T3 Clad

Strength: The Al 2024-T3 clad tests results (Figures B1 thru B3 in Appendix B) display a statistically significant increase in TUS for the PLCRS Nd YAG lasers (Clean and Quantel) results; however, there is a statistically significant decrease in strength for

the carbon dioxide (CO<sub>2</sub>) laser results. A statistically significant decrease in TYS was seen in the PLCRS CO<sub>2</sub> laser and DMB (2) paint removal methods. The yield strength variation for the other paint removal methods was not statistically significant.

Percentage of Elongation: The elongation for the PLCRS CO<sub>2</sub> and Nd YAG (Quantel) laser and DMB method show statistical difference compared to the baseline data. The PLCRS Nd YAG (Cleanlaser) elongation is statistically significant lower than the baseline data.

### **5.1.3 7075-T6 Bare**

Strength: The Al 7075-T6 bare tests results (Figures B4 to B6 in Appendix B) show a statistically significant increase in TUS for the PLCRS CO<sub>2</sub> and Nd YAG (Quantel) laser paint removal methods and a decrease in TUS for the DMB data in reference (2). No difference in TUS using in the PLCRS Nd YAG (Cleanlaser) strength results was observed. The PLCRS laser TYS results show no statistical difference. The DMB (2) yield strength results show a statistical decrease compared to baseline data.

Percentage of Elongation: No statistical significant difference was noted.

### **5.1.4 7075-T6 Clad**

Strength: The Al7075-T6 clad test results (Figures B7 to B9 in Appendix B) display an increase in the TUS for the PLCRS laser paint removal methods and a statistical decrease in the DMB (2) paint removal method. The TYS, using PLCRS lasers, did not change, but the DMB paint removal method produced a decrease.

Percentage of Elongation: The elongation results displayed no difference for the PLCRS CO<sub>2</sub> and Nd YAG (Quantel) laser and DMB (2) paint removal methods. The Nd YAG (Cleanlaser) laser paint removal method produced a decrease in elongation.

### **5.1.5 Summary**

A summary of the PLCRS tensile results and the reference data is shown in Table 1. The space marked “+” indicates a statistically significant increase in the property, while “-” indicates a decrease. It should be noted, that although there may be a statistically significant difference at the 90% confidence level, there may not be a significant engineering difference. The differences observed are small and well within the expected scatter in material properties. This scatter has been accounted for in the design of the aircraft and should not be cause for alarm. It should also be noted that the Laser Stripping Methods showed a lesser, if any, reduction of tensile properties. The Laser Stripping Methods tensile properties are above the MMPDS ‘A’ allowable.

**Table 1. Tensile Properties for Various Paint Stripping Methods**

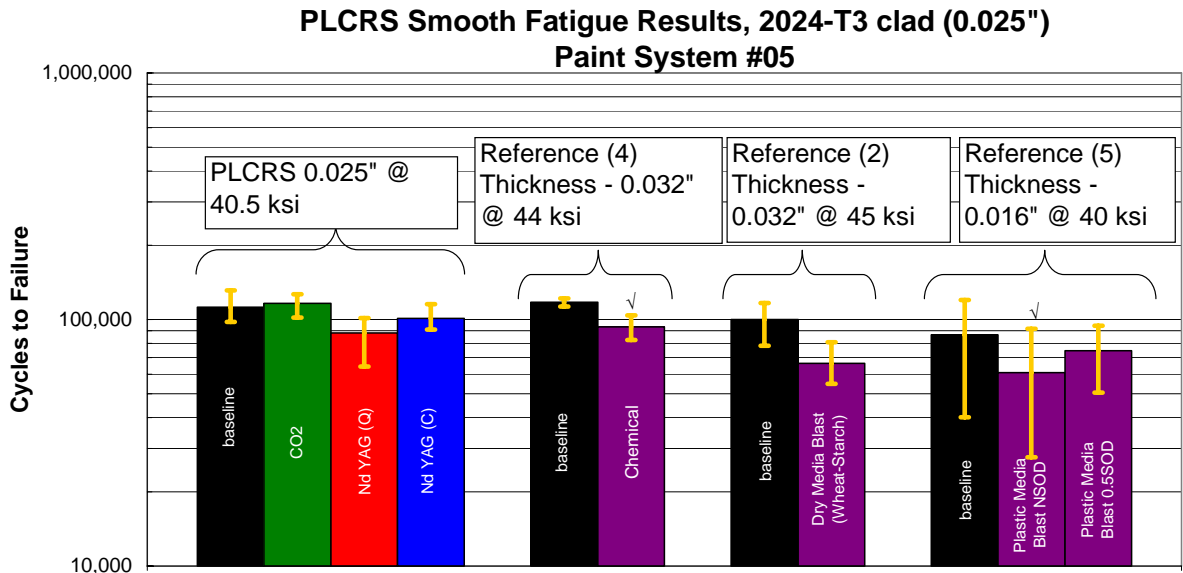
| Paint Removal Methods                        | Al 2024-T3 bare |     |    | Al 2024-T3 clad |     |    | Al 7075-T6 bare |     |    | Al 7075-T6 clad |     |    |
|--|-----------------|-----|----|-----------------|-----|----|-----------------|-----|----|-----------------|-----|----|
|  | Tension         |     |    | Tension         |     |    | Tension         |     |    | Tension         |     |    |
| Reference                                    | UTS             | YTS | %E | UTS             | YTS | %E | UTS             | YTS | %E | UTS             | YTS | %E |
| (2), DMB (wheat starch)                      | -               | -   | NS | -               | -   | NS | -               | -   | NS | -               | -   | NS |
| (3), Plasma Etching                          | -               | NS  | -  |                 |     |    |                 |     |    |                 |     |    |
| (3), Excimer                                 | -               | NS  | -  |                 |     |    |                 |     |    |                 |     |    |
| (1), (3), CO2 Laser                          | +               | NS  | +  |                 |     |    |                 |     |    |                 |     |    |
| (3), Nd YAG                                  | -               | NS  | -  |                 |     |    |                 |     |    |                 |     |    |
| <b>PLCRS</b>                                 |                 |     |    |                 |     |    |                 |     |    |                 |     |    |
| CO2  | +               | NS  | NS | -               | -   | NS | +               | NS  | NS | +               | NS  | NS |
| Nd YAG (Q)                                   | +               | NS  | NS | +               | NS  | NS | +               | NS  | NS | +               | NS  | NS |
| Nd YAG (C)                                   | +               | NS  | -  | +               | NS  | -  | NS              | NS  | NS | +               | NS  | -  |
| NS – No Statistically Significant Difference |                 |     |    |                 |     |    |                 |     |    |                 |     |    |
| - - Statistically Significant Decrease       |                 |     |    |                 |     |    |                 |     |    |                 |     |    |
| + - Statistically Significant Increase       |                 |     |    |                 |     |    |                 |     |    |                 |     |    |
| - No tabulated reference data found          |                 |     |    |                 |     |    |                 |     |    |                 |     |    |

**5.2 Fatigue Results**

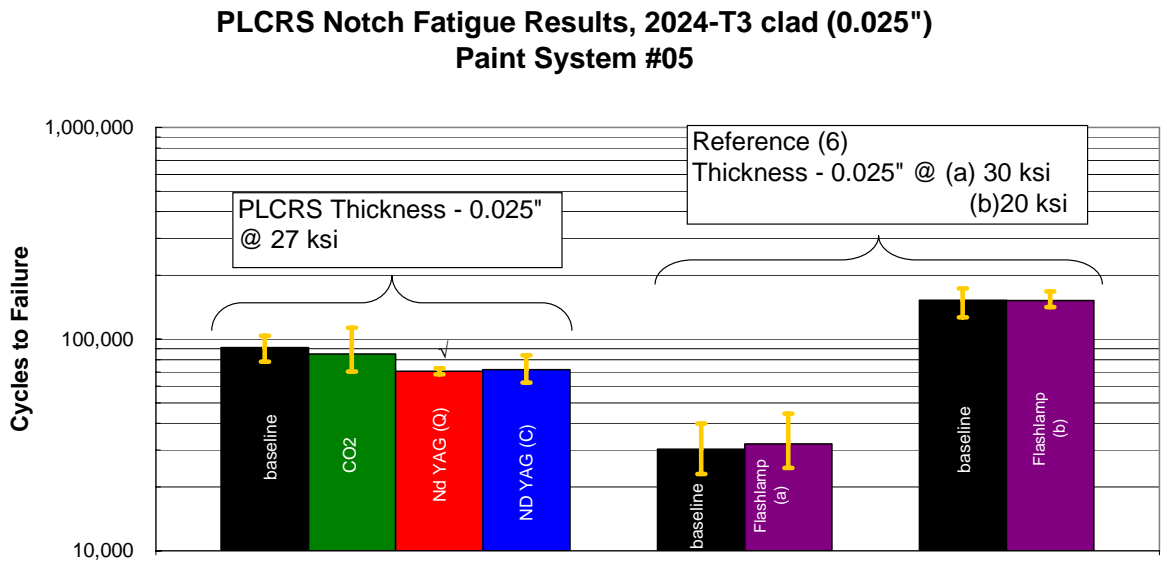
An important point to consider when viewing any fatigue data is the inherent scatter in fatigue life for any material and condition. Depending on the stress level, normal scatter in the fatigue life of metallic materials can easily range over a decade in cyclic life, witnessed in the numerous fatigue publications such as the MMPDS handbook. Differences in fatigue life of 20% are well within the norm, particularly when fatigue stresses approach the endurance strength of the material. In general, fatigue data is assumed to follow a log-normal distribution and therefore plotted and analyzed in terms of the log cycles. Thus, differences in cyclic lives of 20% and perhaps even 50%-60%, while statistically significant, may not be as significant from an engineering standpoint. Such debits or variability in fatigue life are generally design specific and best left to the design engineer to ascertain whether slight decreases in life are significant from an engineering standpoint.

The PLCRS and the reference fatigue data are displayed as bar charts in Figures 4 and 5. The average cycles-to-failure of at least five replicates for each baseline and paint removal method are presented in the graphs. The brackets on each bar represent the observed cycles-to-failure range of the replicates tested at the given stress level. The baseline data for the PLCRS and the reference data is the black bar that appear to the left in each plot. The bars next to the baseline information are the paint removal test results labeled by the removal method. The report reference number is displayed over the bar. A statistical significant difference is indicated by a ‘√’ mark. A data set without a ‘√’ mark indicates no statistical difference at a 90% confidence level.

The 2024-T3 clad material fatigue results are displayed in Figures 4 and 5. The fatigue results for the remaining materials are located in Appendix C (Figures C1 to C3).



**Figure 4. 2024-T3 Clad S-N Smooth Fatigue Results.** ✓ indicate a statistically significant difference.



**Figure 5. 2024-T3 Clad S-N Notch Fatigue Results.** ✓ indicate a statistical significant difference.

### 5.2.1 2024-T3 Clad Smooth Fatigue

2024-T3 clad smooth fatigue results from the PLCRS program showed no statistically significant difference in fatigue life for the CO<sub>2</sub> and Nd YAG (Cleanlaser)

laser paint removal method. The Nd YAG (Quantel) laser paint and Chemical (reference (4)), and PMB NSOD (reference (5)) removal method showed a statistically significant decrease in fatigue life. Data from reference (2) (DMB) and (5) (PMB) paint removal method displayed no statistically significant difference in fatigue life.

### **5.2.2 2024-T3 Clad Notch Fatigue**

The notch fatigue results for 2024-T3 clad from the Nd YAG (Quantel and Cleanlaser) paint removal method showed a statistically significant reduction in fatigue life. The CO<sub>2</sub> and flash lamp paint removal method (reference (6)) showed no statistically significant difference in fatigue life.

### **5.2.3 7075-T6 Bare Smooth Fatigue**

The 7075-T6 bare smooth fatigue results (Figure C1 in Appendix C) for the CO<sub>2</sub> laser and DMB paint removal methods showed no statistically significant change in fatigue life. The Nd YAG (Quantel and Cleanlaser) laser paint removal method and chemical paint removal method resulted in a statistically significant shorter fatigue life.

### **5.2.4 7075-T6 Bare Notch Fatigue**

7075-T6 bare notch fatigue results (Figure C4 in Appendix C) for the PLCRS project show a statistically significant decrease in fatigue life for the CO<sub>2</sub> and Nd YAG (Quantel and Cleanlaser) laser paint removal methods. No tabulated data was found for 7075-T6 bare notch fatigue in the reference data reports.

### **5.2.5 7075-T6 Clad Smooth Fatigue**

7075-T6 clad smooth fatigue results (Figure C3 in Appendix C) showed no statistically significant change in fatigue life for the PLCRS lasers and PMB. Chemical strip and DMB showed a statistically significant decrease in fatigue life.

### **5.2.6 7075-T6 Clad Notch Fatigue**

The notch fatigue results for 7075-T6 clad for the Nd YAG (Cleanlaser and Quantel) paint removal method showed a statistically significant reduction in fatigue life. The CO<sub>2</sub> and flash lamp paint removal method (reference (6)) showed no statistically significant difference in fatigue life.

### **5.2.7 Summary**

A qualitative summary of the PLCRS fatigue results and the reference data is listed in Table 2. The space marked “+” indicates a statistically significant increase, while “-” indicates a statistically significant decrease. Note that all differences fall well within the normal scatter in fatigue life, approximately one decade. Therefore, the differences are not significant from an engineering standpoint.

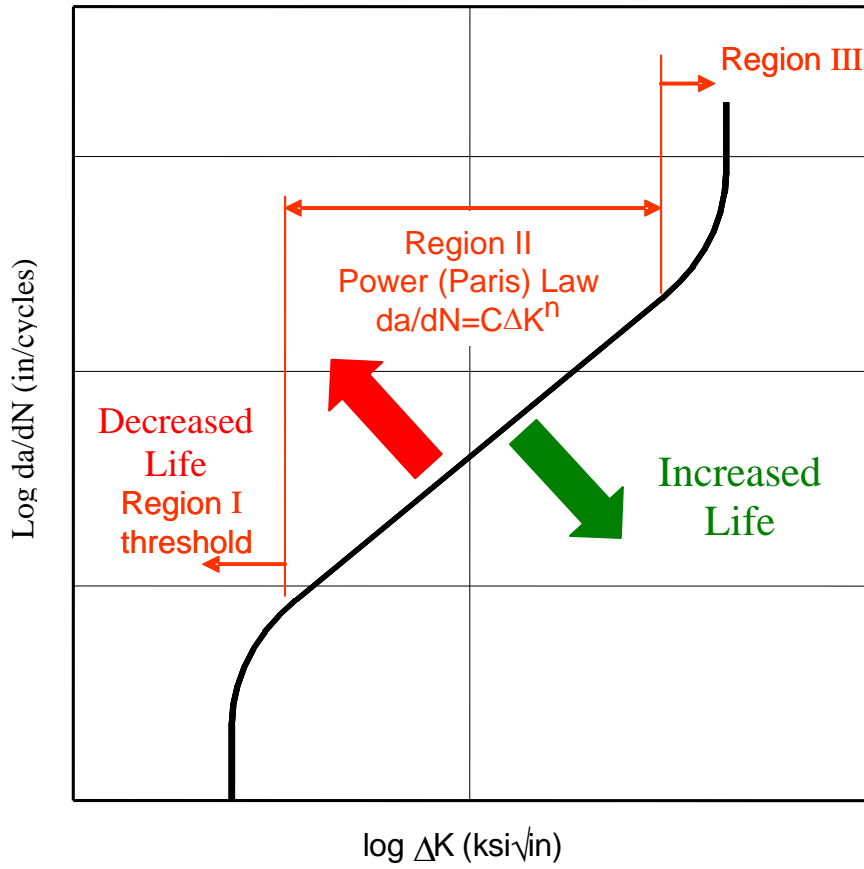
**Table 2. Fatigue Properties**

| Paint Removal Methods                        | 2024-T3 Clad                        |       | 7075-T6 Bare |       | 7075-T6 Clad |       |
|--|-------------------------------------|-------|--------------|-------|--------------|-------|
|  | Smooth                              | Notch | Smooth       | Notch | Smooth       | Notch |
| (4), Chemical                                | -                                   |       | -            |       | -            |       |
| (2),DMB (Wheat Starch)                       | -                                   |       |              |       | -            |       |
| (5), PMB (Plastic)                           | -                                   |       |              |       | NS           |       |
| (6), Flash lamp                              |                                     | NS    |              | +     |              | +     |
| <b>PLCRS</b>                                 |                                     |       |              |       |              |       |
| CO <sub>2</sub>                              | NS                                  | NS    | +            | -     | NS           | NS    |
| Nd YAG (Q)                                   | -                                   | -     | -            | -     | NS           | -     |
| Nd YAG (C)                                   | NS                                  | -     | -            | -     | NS           | -     |
| NS – No Statistically Significant Difference |                                     |       |              |       |              |       |
| - Statistically Significant Decrease         |                                     |       |              |       |              |       |
| + Statistically Significant Increase         |                                     |       |              |       |              |       |
|  | - No tabulated reference data found |       |              |       |              |       |

### 5.3 Fatigue Crack Growth Rate (FCGR) Testing

Fatigue crack growth rate (FCGR) data aid in determining the life of a component containing cracks, as well as determining inspection intervals for the component. If crack growth rates are increased significantly by a process such as paint removal, the inspection interval may have to be reduced, leading to more frequent inspections. However, if crack growth rates are not significantly affected, the original inspection intervals are presumably still appropriate. As the crack length increases during fatigue cycling, the rate of crack propagation increases (change in crack length/ change in fatigue cycles, or da/dN) due to an increase in the range of stress intensity factor,  $\Delta K$ , which is a function of both crack length and stress amplitude. The magnitude of  $\Delta K$  (units of ksi $\sqrt{\text{in}}$ ) controls the rate of crack propagation and, with the knowledge of the expected fatigue loading and material properties, one can estimate the life of a cracked structure.

The plot in Figure 6 represents typical FCGR data. This sigmoidal shaped curve has three distinct regions: Region 1 (threshold), Region 2 (linear or ‘power law’ region), and Region 3 (onset of fast fracture). The linear relationship between the logarithm of da/dN and the logarithm of the stress intensity range is generally modeled as a power fit to the actual data and also termed the “Paris Region” after the researcher who first identified this relationship. Data which falls above the curve in Figure 6 indicates a higher crack propagation rate and thus identified as ‘Decreased Life’. Conversely, data falling below and to the right of the idealized curve would be have lower propagation rates and thus result in ‘Increased Life’.



**Figure 6. Example Plot of FCGR Data.**

This effort evaluated the effect of the various laser paint removal processes on the crack growth rate of the metallic substrates along with baseline (un-stripped) samples. Each baseline and paint removal method had at least four replicates. An example of this for the 2024-T3 substrate is shown in Figure 7. Data for all substrates are further illustrated in Figures D1 to D4 in Appendix D.

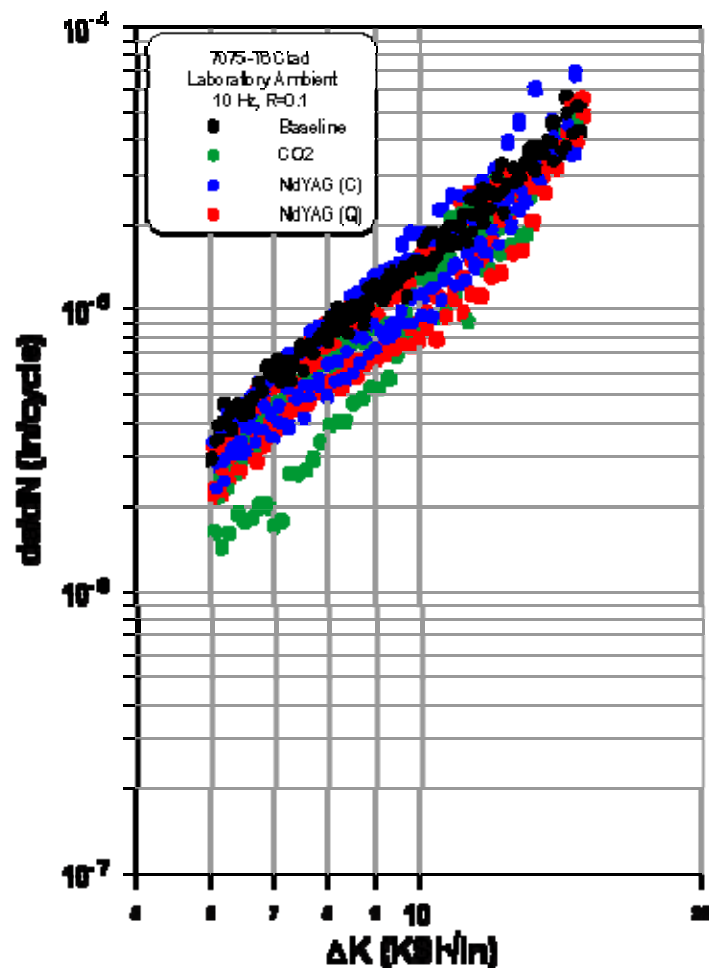


Figure 7. 7075-T6 Clad Fatigue Crack Growth Rate Test Results.

### 5.3.1 FCGR Statistical Analysis

Since any reference FCGR data could not be found in a tabulated format, it is impossible to compare reference paint removal methods with the PLCRS data. The statistical analysis performed on the PLCRS data was accomplished by first modeling the Paris region for each removal technique and substrate and examining the statistical variation in growth rates at a 90% confidence level at two distinct  $\Delta K$  values: 6 and 14 ksi $\sqrt{\text{in}}$ . Table 3 shows the results of this statistical analysis for all of the FCGR tests performed in the PLCRS project. The results of this analysis are further depicted graphically in Figure 8, where the Paris model is shown along with the  $\pm 90\%$  confidence levels. When the confidence levels of a particular data set fall below the baseline curve, a statistically significant decrease in growth rate is noted, beneficially from a life standpoint. Further more, when the confidence intervals are above the baseline, there is a statistical increase in growth rates which corresponds to a decrease in fatigue crack growth life. When the confidence intervals of two data sets overlap, no statistical differences are noted. For the 7075-T6 clad data represented in Figure 8, all the paint strip data at 6 ksi $\sqrt{\text{in}}$  fall below the baseline, indicating lower growth rates. At 14 ksi $\sqrt{\text{in}}$ , no statistical differences are noted between the stripped data and the baseline with the exception of the Nd YAG (Q) which is statistically lower than baseline.

Reviewing the data shown in Table 3 indicates that from a statistical standpoint, only the 2024-T3 clad data showed a decrease in growth rate resistance (i.e., higher growth rates) over baseline material. The significance of this difference (and all differences) noted in Table 3 from an engineering standpoint is discussed in the following section.

### 5.3.2 FCGR Data Analysis using ASTM E647

It is not unusual for FCGR data to show a large amount of specimen- to-specimen variability. ASTM E 647-00, *Standard Test Method for Measurement of Fatigue Crack Growth Rates*<sup>1</sup>, in Section 8.1 states that:

At crack growth rates greater than  $10^{-8}$  m/cycle, the within-lot variability (neighboring specimens) of  $da/dN$  at a given  $\Delta K$  typically can cover about a factor of two. At rates below  $10^{-8}$  m/cycle, the variability in  $da/dN$  may increase to about a factor of five or more due to increased sensitivity of  $da/dN$  to small variations in  $\Delta K$ . This scatter may be increased further by variables such a micro structural difference, residual stresses, changes in crack tip geometry (crack branching) or near tip stress . . .

Furthermore, the standard states:

... the reproducibility in  $da/dN$  within a laboratory to average  $\pm 27\%$  and range from  $\pm 13$  to  $\pm 50\%$ , depending on laboratory...

---

<sup>1</sup> Section 3, Metals Test Methods and Analytical Procedures, ASTM International, West Conshohocken, PA.

**Table 3. Statistical Analysis of Fatigue Crack Growth Rate Data Results for PLCRS**

| <b>Material</b>            | <b>Paint Removal Method</b> | <b>ΔK ksi-(in)<sup>0.5</sup></b> | <b>Predicted Value From Model</b> | <b>Lower 90% Confidence Interval</b> | <b>Upper 90% Confidence Interval</b> | <b>Statistical Significance</b> | <b>Predicted Value – Baseline Predicted Value</b> |
|----------------------------|-----------------------------|----------------------------------|-----------------------------------|--------------------------------------|--------------------------------------|---------------------------------|---|
| <b><u>2024-T3 Clad</u></b> | <b>Baseline</b>             | <b>6</b>                         | <b>-6.163</b>                     | <b>-6.184</b>                        | <b>-6.141</b>                        |                                 |   |
|                            |                             | <b>14</b>                        | <b>-4.879</b>                     | <b>-4.906</b>                        | <b>-4.852</b>                        |                                 |   |
|                            | Q Laser                     | 6                                | -6.137                            | -6.146                               | -6.129                               |                                 | 0.0254  |
|                            |                             | 14                               | -4.664                            | -4.676                               | -4.652                               | -                               | 0.215   |
|                            | C Laser                     | 6                                | -6.126                            | -6.137                               | -6.114                               | -                               | 0.0370  |
|                            |                             | 14                               | -4.689                            | -4.708                               | -4.670                               | -                               | 0.190   |
|                            | CO <sub>2</sub>             | 6                                | -6.256                            | -6.277                               | -6.235                               | +                               | -0.0930   |
|                            |                             | 14                               | -4.783                            | -4.813                               | -4.754                               | -                               | 0.0961  |
| <b><u>7075-T6 Clad</u></b> | <b>Baseline</b>             | <b>6</b>                         | <b>-5.366</b>                     | <b>-5.377</b>                        | <b>-5.354</b>                        |                                 |   |
|                            |                             | <b>14</b>                        | <b>-4.339</b>                     | <b>-4.354</b>                        | <b>-4.324</b>                        |                                 |   |
|                            | Q Laser                     | 6                                | -5.484                            | -5.508                               | -5.460                               | +                               | -0.118  |
|                            |                             | 14                               | -4.435                            | -4.469                               | -4.402                               | +                               | -0.0964   |
|                            | C Laser                     | 6                                | -5.447                            | -5.473                               | -5.422                               | +                               | -0.0818   |
|                            |                             | 14                               | -4.347                            | -4.385                               | -4.309                               | NS                              | -0.00786  |
|                            | CO <sub>2</sub>             | 6                                | -5.584                            | -5.615                               | -5.553                               | +                               | -0.218  |
|                            |                             | 14                               | -4.361                            | -4.411                               | -4.311                               | NS                              | -0.0220   |
| <b><u>7075-T6 Bare</u></b> | <b>Baseline</b>             | <b>6</b>                         | <b>-5.456</b>                     | <b>-5.474</b>                        | <b>-5.439</b>                        |                                 |   |
|                            |                             | <b>14</b>                        | <b>-4.259</b>                     | <b>-4.283</b>                        | <b>-4.236</b>                        |                                 |   |
|                            | Q Laser                     | 6                                | -5.552                            | -5.571                               | -5.533                               | +                               | -0.0955   |
|                            |                             | 14                               | -4.250                            | -4.279                               | -4.222                               | NS                              | 0.00892   |
|                            | C Laser                     | 6                                | -5.671                            | -5.707                               | -5.634                               | +                               | -0.214  |
|                            |                             | 14                               | -4.202                            | -4.255                               | -4.148                               | NS                              | 0.0574  |
|                            | CO <sub>2</sub>             | 6                                | -5.516                            | -5.539                               | -5.492                               | +                               | -0.0591   |
|                            |                             | 14                               | -4.244                            | -4.284                               | -4.204                               | NS                              | 0.0153  |

+ -Statistically significant difference where the laser FCGR data lies below the baseline

- - Statistically significant difference where the laser FCGR data lies above the baseline

NS No statistical significance

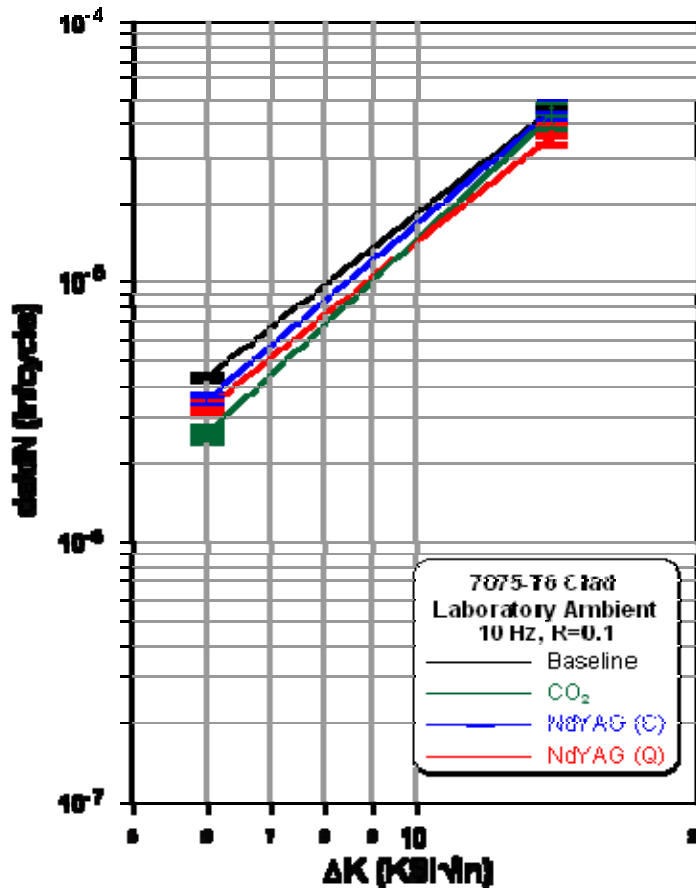


Figure 8. Statistical Representation of FCGR data for 7075-T6 Clad.

Thus the statistical differences shown in Table 3 should thus be viewed with this in mind. The data comparisons are made at the discrete  $\Delta K$  levels of 6 and 14 ksi√in. The corresponding levels of  $da/dN$  are in the range of  $1 \times 10^{-4}$  to  $1 \times 10^{-6}$  in/cyc. Per the ASTM E647 standard, differences within a factor of two to five between data sets can be expected due to specimen-to-specimen variability. Therefore, since the data in Table 3 (shown as  $\log da/dN$ ) does not vary by more than a factor of two, differences from the baseline should be considered expected variability. As none of the data meet this criterion, there does not appear to be significant differences from an engineering standpoint between the baseline and FCGR data for any of the three examined substrates.

## 5.4 Superficial Hardness

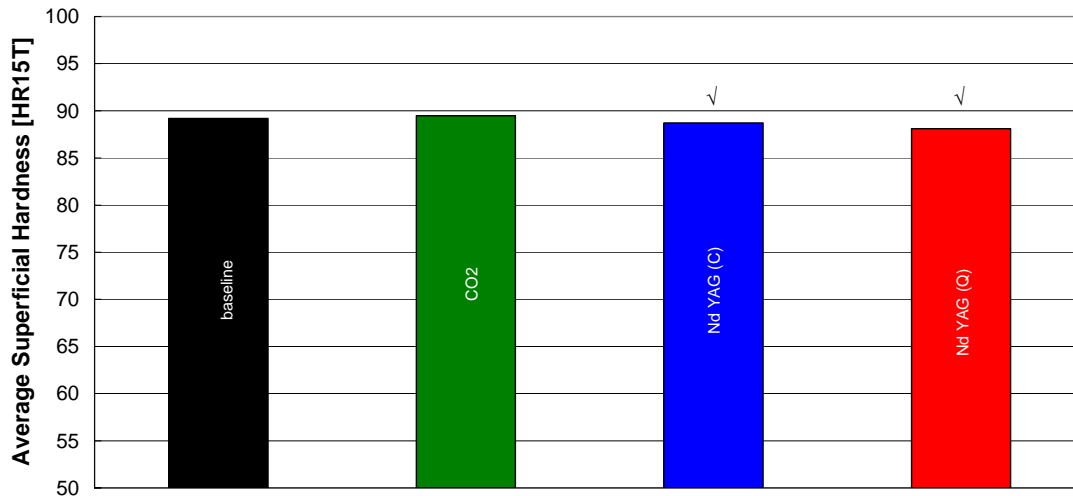
The statistical analysis for the PLCRS hardness for 2024-T3 and 7075-T6 clad are shown in Table 4 and Figures 9 and 10. The statistical significant difference at a 90% simultaneous confidence interval for each paint removal method is indicated by a ‘√’ mark. A data set without a ‘√’ mark indicates no difference.

Both YAG lasers decreased the hardness; CO<sub>2</sub> no change for both 7075-T6 and 2024-T3.

**Table 4. Statistical Analysis of Hardness**

| Paint Removal Method | 2024-T3              | 7075-T6              |
|----------------------|----------------------|----------------------|
| <u>PLCRS</u>         | Superficial Hardness | Superficial Hardness |
| Baseline             | <b>82.6</b>          | <b>89.2</b>          |
| CO <sub>2</sub>      | 82.1                 | 89.5                 |
| Nd YAG ( Q )         | 81.5                 | 88.1                 |
| Nd YAG ( C )         | 80.9                 | 88.7                 |

**PLCRS Superficial Hardness Results, 7075-T6**



**Figure 9. 7075-T6 Clad Superficial Hardness Results.**

### PLCRS Superficial Hardness Results, 2024-T3

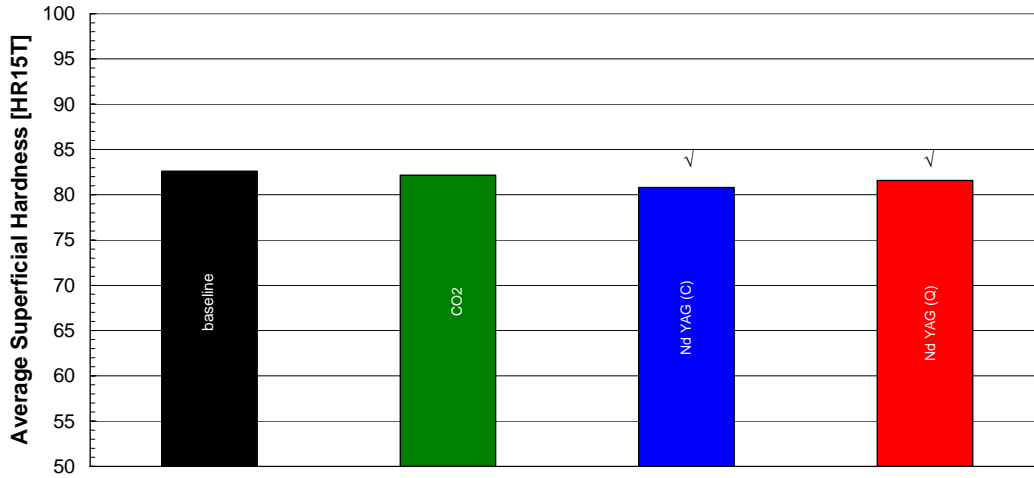




Figure 10. 2024-T3 Superficial Hardness Results. √ indicate a statistical difference at a 90% confidence level.

### 5.5 Conclusions/Observations

Table 5 summarizes the effects of the paint removal methods on the mechanical properties of the metallic substrates. No conclusive data depict one paint removal method to be better or worse than the others. The statistical significance presented may not represent an engineering significance. Most of the metallic tension mean levels (TUS, TYS, percentage of elongation) are above the ‘A’ Allowable given in the MMPDS Handbook. The most notable view from this study was how few mechanical property tests data were published on the past paint removal methods.

**Table 5. Metallic Matrix for Paint Removal Methods**

| Paint Removal Methods                    | Material - 2024-T3 Bare |     |        |         |         | Material - 2024-T3 Clad |     |        |         |         | Material - 7075-T6 Clad |     |        |         |         | Material - 7075-T6 Bare 0.016" |     |        |         |         |
|--|-------------------------|-----|--------|---------|---------|-------------------------|-----|--------|---------|---------|-------------------------|-----|--------|---------|---------|--------------------------------|-----|--------|---------|---------|
|  | Tensile                 |     |        | Fatigue |         | Tensile                 |     |        | Fatigue |         | Tensile                 |     |        | Fatigue |         | Tensile                        |     |        | Fatigue |         |
|  | UTS                     | YTS | %Elong | Smooth  | Notched | UTS                     | YTS | %Elong | Smooth  | Notched | UTS                     | YTS | %Elong | Smooth  | Notched | UTS                            | YTS | %Elong | Smooth  | Notched |
| Chemical<br>(Reference (4))              |                         |     |        |         |         |                         |     |        | -       |         |                         |     |        | NS      |         |                                |     |        | -       |         |
| PMB<br>(Reference (5))                   |                         |     |        |         |         |                         |     |        | -       |         |                         |     |        | NS      |         |                                |     |        |         |         |
| DMB (Wheat-Starch)<br>(Reference (2))    | -                       | -   | NS     |         |         | -                       | -   | NS     | NS      |         | -                       | -   | NS     | NS      |         | -                              | -   | NS     | NS      |         |
| Flash Lamp<br>(Reference F)              |                         |     |        |         |         |                         |     |        | NS      |         |                         |     |        | NS      |         |                                |     |        |         |         |
| CO <sub>2</sub> Laser<br>(Reference (1)) | +                       | -   | NS     |         |         |                         |     |        |         |         |                         |     |        |         |         |                                |     |        |         |         |
| Plasma Etching<br>(Reference (3))        |                         |     |        |         |         |                         |     |        |         |         |                         |     |        |         |         |                                |     |        |         |         |
| Excimer<br>(Reference (3))               |                         |     |        |         |         |                         |     |        |         |         |                         |     |        |         |         |                                |     |        |         |         |
| Nd YAG Laser<br>(Reference (3))          |                         |     |        |         |         |                         |     |        |         |         |                         |     |        |         |         |                                |     |        |         |         |
| CO <sub>2</sub> Laser<br>(AFRL Testing)  | +                       | NS  | NS     |         |         | -                       | -   | NS     | NS      | NS      | +                       | NS  | NS     | NS      | NS      | +                              | NS  | NS     | NS      | -       |
| Nd YAG (Q) Laser<br>(AFRL Testing)       | +                       | NS  | NS     |         |         | +                       | NS  | NS     | -       | -       | +                       | NS  | NS     | NS      | -       | +                              | NS  | NS     | -       | -       |
| Nd YAG (C) Laser<br>(AFRL Testing)       | +                       | NS  | -      |         |         | +                       | NS  | -      | NS      | -       | +                       | NS  | -      | NS      | -       | NS                             | NS  | NS     | -       | -       |

+ - Positive Statistical Significance against the baseline material data  
 NS - No Statistical Significance against the baseline material data  
 - - Negative Statistical Significance against the baseline material data  
 - Historical data not found for Statistical Analysis  
 - No fatigue data generated

## 6. COMPOSITE LITERATURE SEARCH RESULTS

The primary focus of the composite literature search was on paint removal testing conducted on composite substrates used by the DoD and in the PLCRS project. The JTP requires the substrate to be run through four paint removal cycles before any mechanical testing is performed on the substrate. Graphite, fiberglass, and Kevlar epoxy were the materials selected for the PLCRS project, so the reference search focused on these materials. The paint removal methods were PMB, high intensity light (flash lamp), and hand (wet/dry) abrasive.

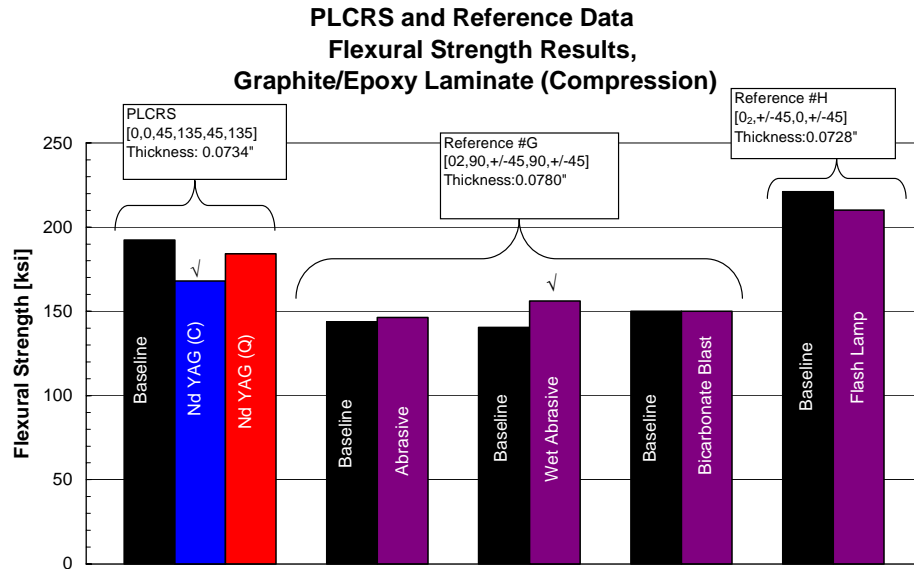
### 6.1 Four-Point Flexural Testing

The PLCRS and the reference data flexural results are displayed in bar charts. Each baseline and paint removal method had at least five replicates with the average flexural strength represented in the graphs. The baseline data for the PLCRS and the reference data are represented by the black bar that appears on the left in each data set. The bars next to the baseline information are the paint removal test results labeled by the removal method. The reference number is displayed over the data from which it was extracted and corresponds to the summary chart in Appendix A. A statistically significant difference in the data between the baseline and the paint removal method at a 90% simultaneous confidence interval is indicated by a ‘√’ mark. A data set without a ‘√’ mark indicates no statistical difference.

Figure 11 shows the results of the PLCRS graphite/epoxy flexural test and the reference data found for that material. Graphs for the other substrates are in Appendix E. The Nd YAG (Cleanlaser) laser results in Figure 11 shows a decrease in flexural strength in comparison to the baseline data. The reference data shows no statistical change in flexural except in the wet abrasive which showed an increase.

Figure E1 displays the PLCRS flexural strength results for the graphite, fiberglass and Kevlar epoxy laminate tests. The fiberglass results show a decrease in flexural strength for both Nd YAG lasers compared to the baseline. The Kevlar results showed no difference between the Nd YAG lasers.

Figure E2 displays the PLCRS and a PMB reference data graphite/epoxy laminate flexural strength results. Only the four cycles PMB at 38 and 60 psi showed a decrease in strength.



**Figure 11. Graphite/Epoxy Flexural Strength Results.** √ indicates a statistical significant difference at a 90% confidence level.

A matrix of the PLCRS composite flexural strength results and the reference data is presented in Table 6. The space marked “+” indicates an increase (at a 90% confidence interval) in the flexural strength, while “-” indicates a decrease.

## 6.2 Summary

The results of tests conducted to compare paint removal methods were inconclusive. The data did not depict one paint removal method to be better or worse than the other methods. Any indicated statistically significant difference may not represent an engineering significance. The most notable finding from this study was how few mechanical property tests data have been published on presented past paint removal methods.

**Table 6. Matrix for Composite Flexural Data**

| Paint Removal Method             | Graphite/Epoxy                      | Fiber Glass/Epoxy | Kevlar/Epoxy      |
|----------------------------------|-------------------------------------|-------------------|-------------------|
| <b><u>Reference</u></b>          | Flexural Strength                   | Flexural Strength | Flexural Strength |
| #H Flash Lamp                    | NS                                  |                   |                   |
| #E PMB (Plastic)                 | NS                                  |                   |                   |
| #G Bicarbonate Blast             | NS                                  |                   |                   |
| #G Abrasive                      | NS                                  |                   |                   |
| #G Wet Abrasive                  | +                                   |                   |                   |
| <b><u>PLCRS</u></b>              |                                     |                   |                   |
| Nd YAG (Q)                       | NS                                  | -                 | NS                |
| Nd YAG (C)                       | -                                   | -                 | NS                |
| NS – No Statistical Significance |                                     |                   |                   |
| - - Statistical decrease         |                                     |                   |                   |
| + - Statistical increase         |                                     |                   |                   |
|                                  | - No tabulated reference data found |                   |                   |

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**APPENDIX A**

**LASER PAINT STRIPPING REFERENCE LITERATURE  
SUMMARY**

## **Laser Paint Stripping Literature Catalog**

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**APPENDIX B**  
**TENSILE RESULTS**

90% C.I. Statistical Significance - ✓

### PLCRS and Reference Data Average Ultimate Tensile Strength Results, 2024-T3 Clad

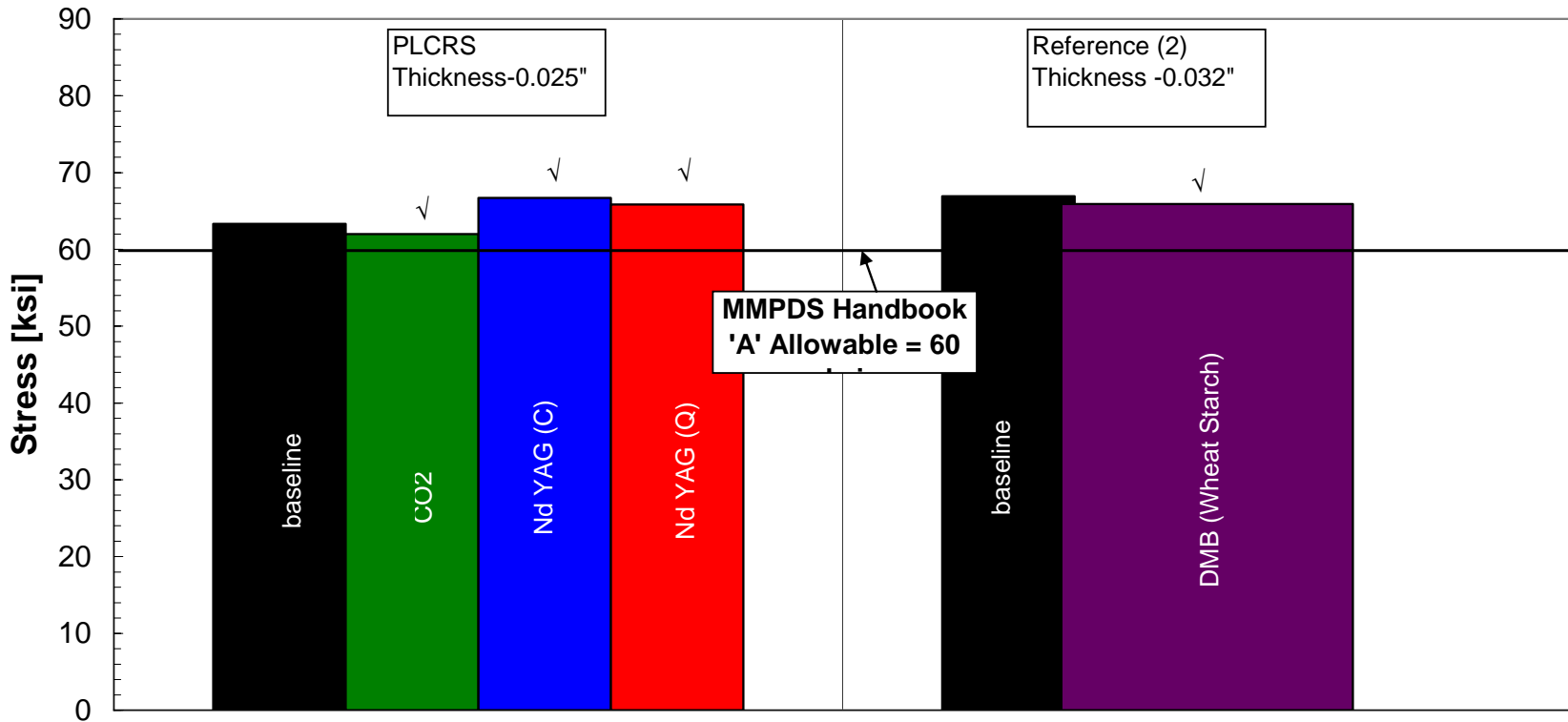


Figure B1. PLCRS and Reference Data Metallic Al 2024-T3 Clad Ultimate Tensile Strength Results.

90% C.I. Statistical Significance -  $\checkmark$

### PLCRS and Reference Data Average Yield Tensile Strength Results, 2024-T3 Clad

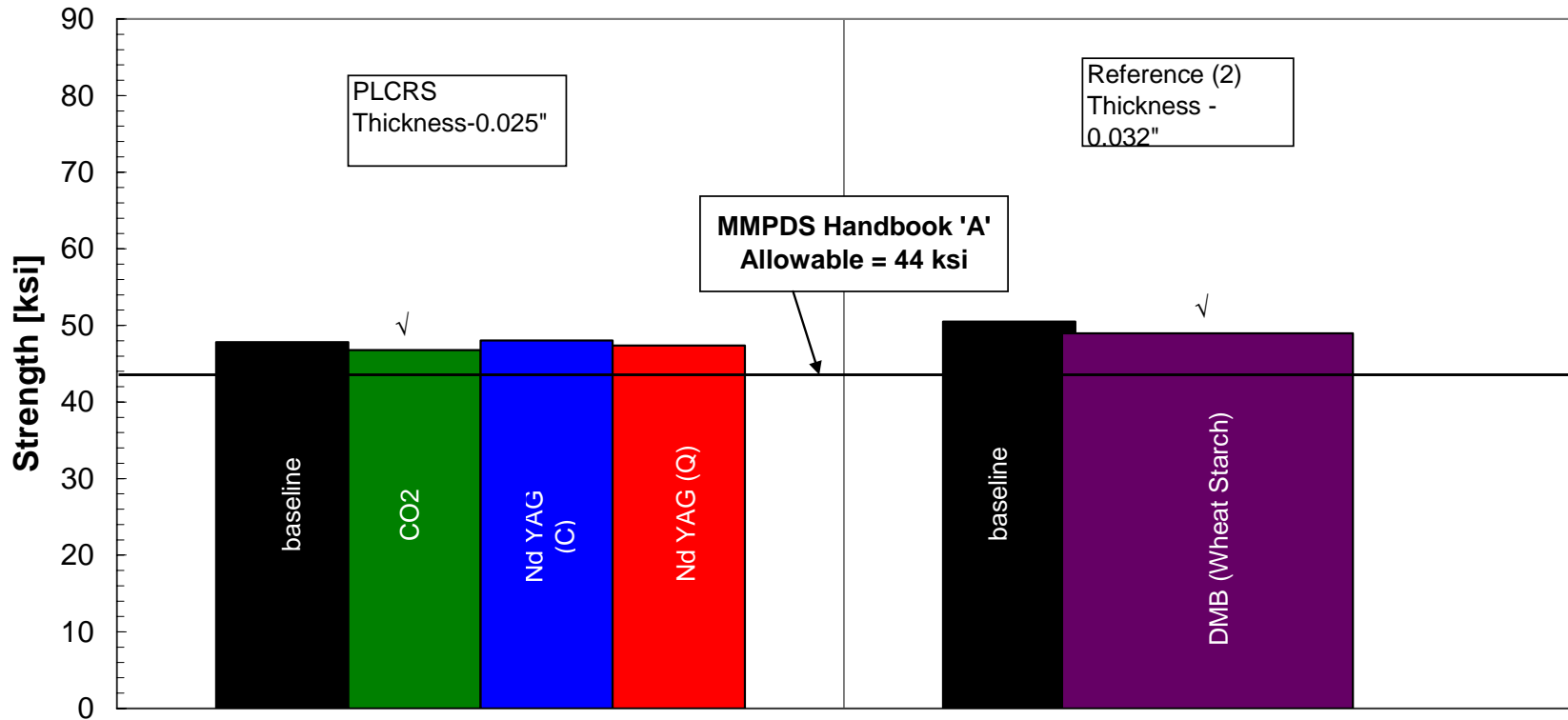


Figure B2. PLCRS and Reference Data Metallic Al2024-T3 Clad Yield Tensile Strength Results.

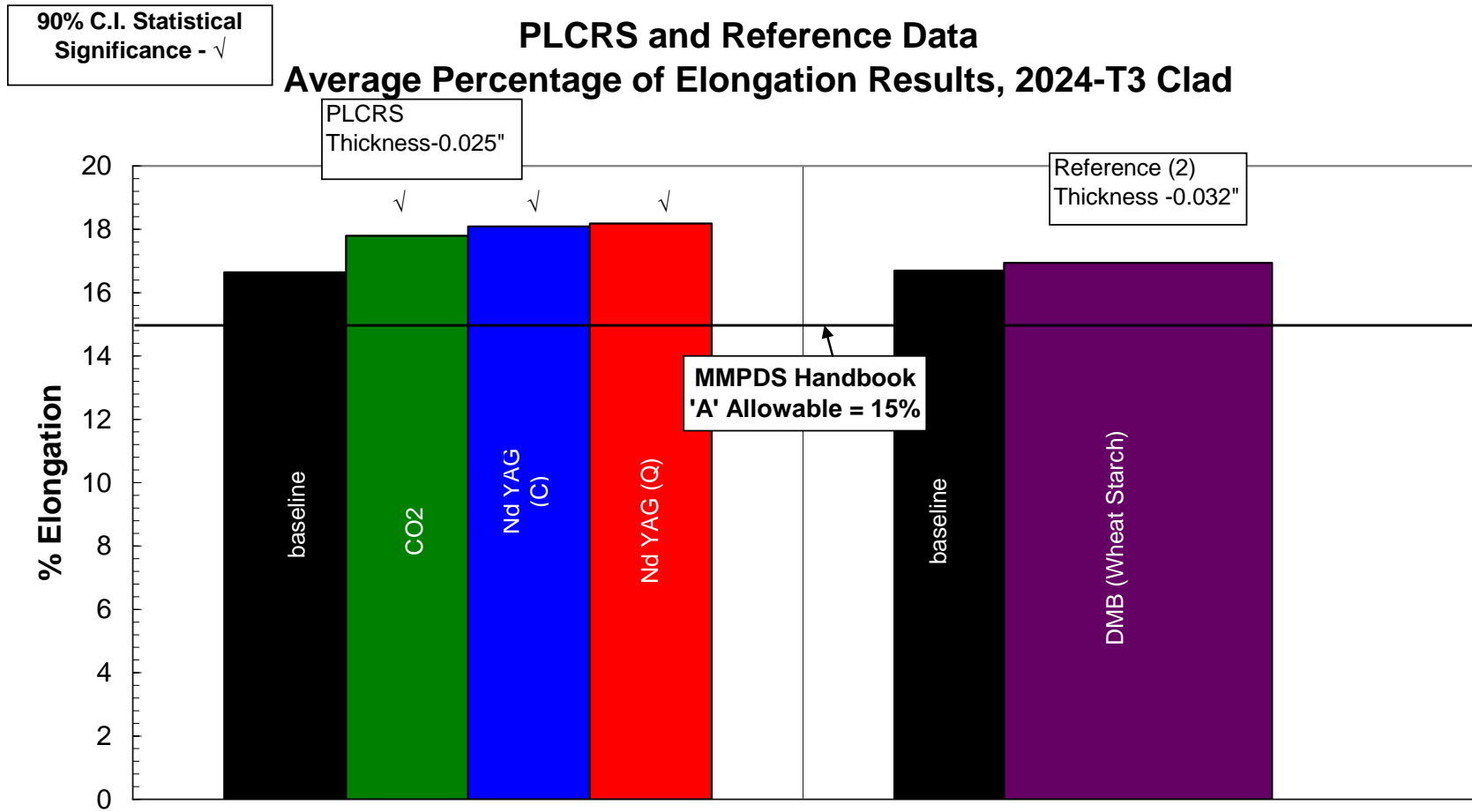


Figure B3. PLCRS and Reference Data Metallic Al2024-T3 Clad Elongation Results.

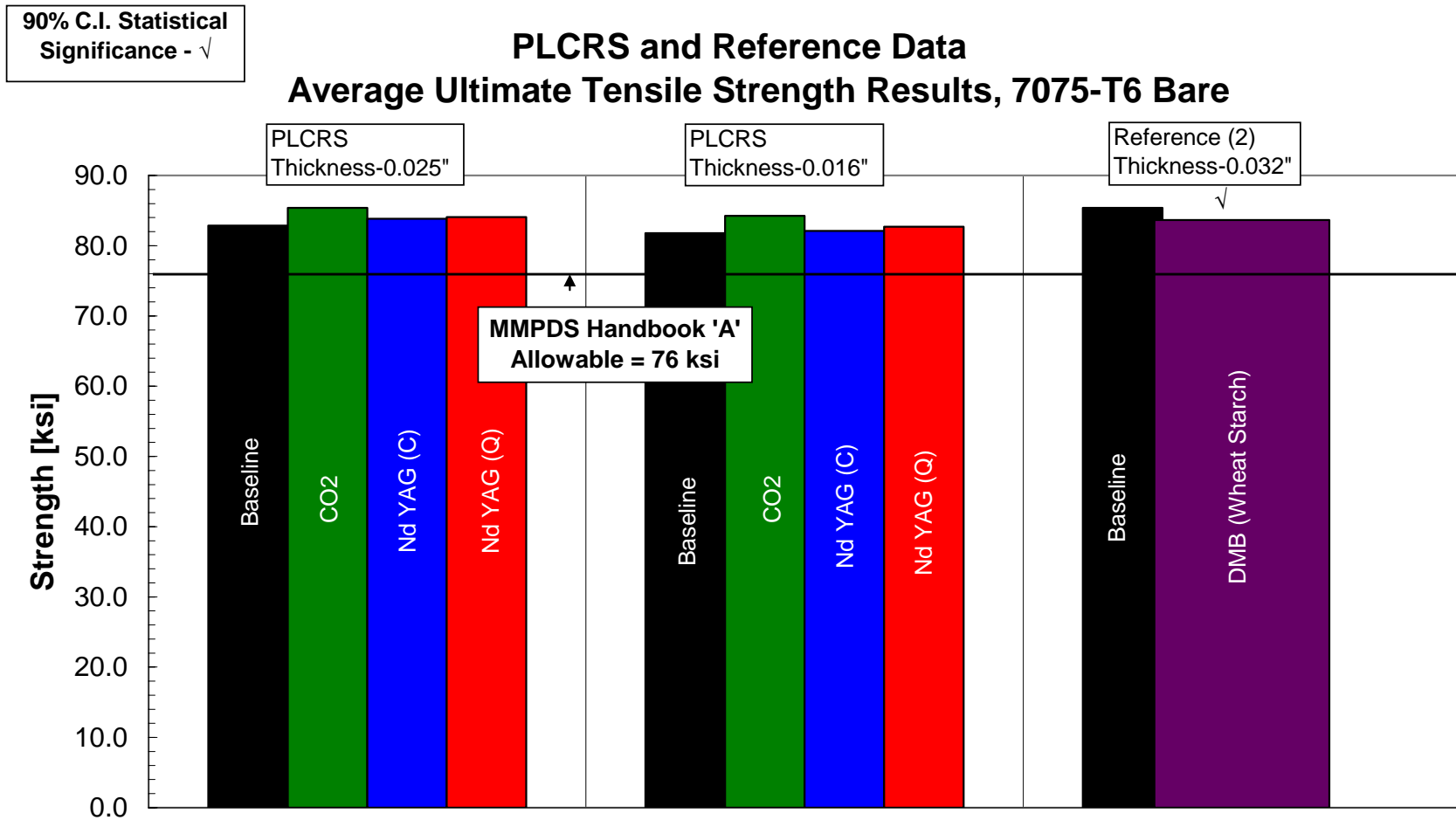


Figure B4. PLCRS and Reference Data Metallic Al7075-T6 Bare Ultimate Tensile Strength Results.

90% C.I. Statistical Significance - ✓

### PLCRS and Reference Data Average Yield Tensile Strength Results, 7075-T6 Bare

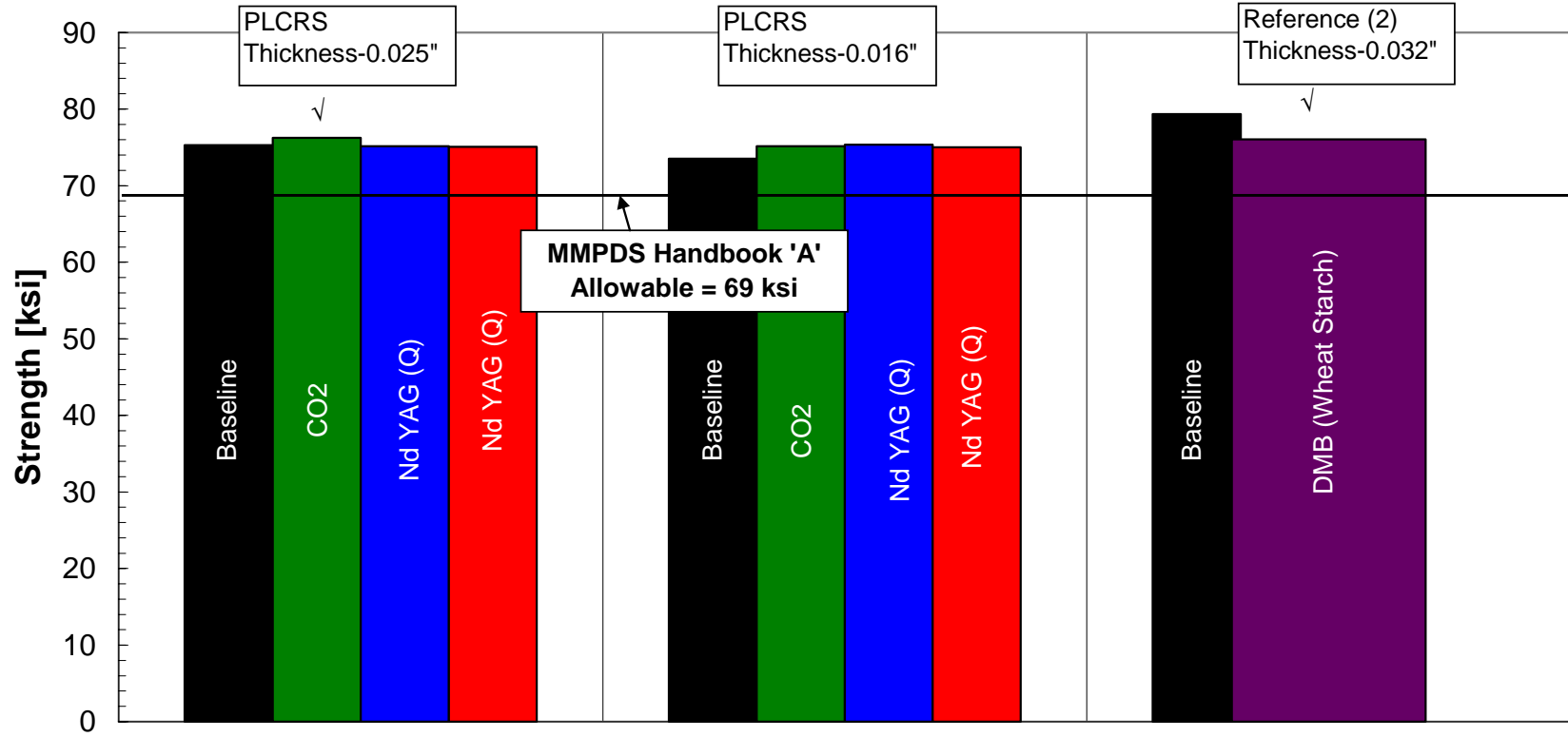


Figure B5. PLCRS and Reference Data Metallic Al7075-T6 Bare Yield Tensile Strength Results.

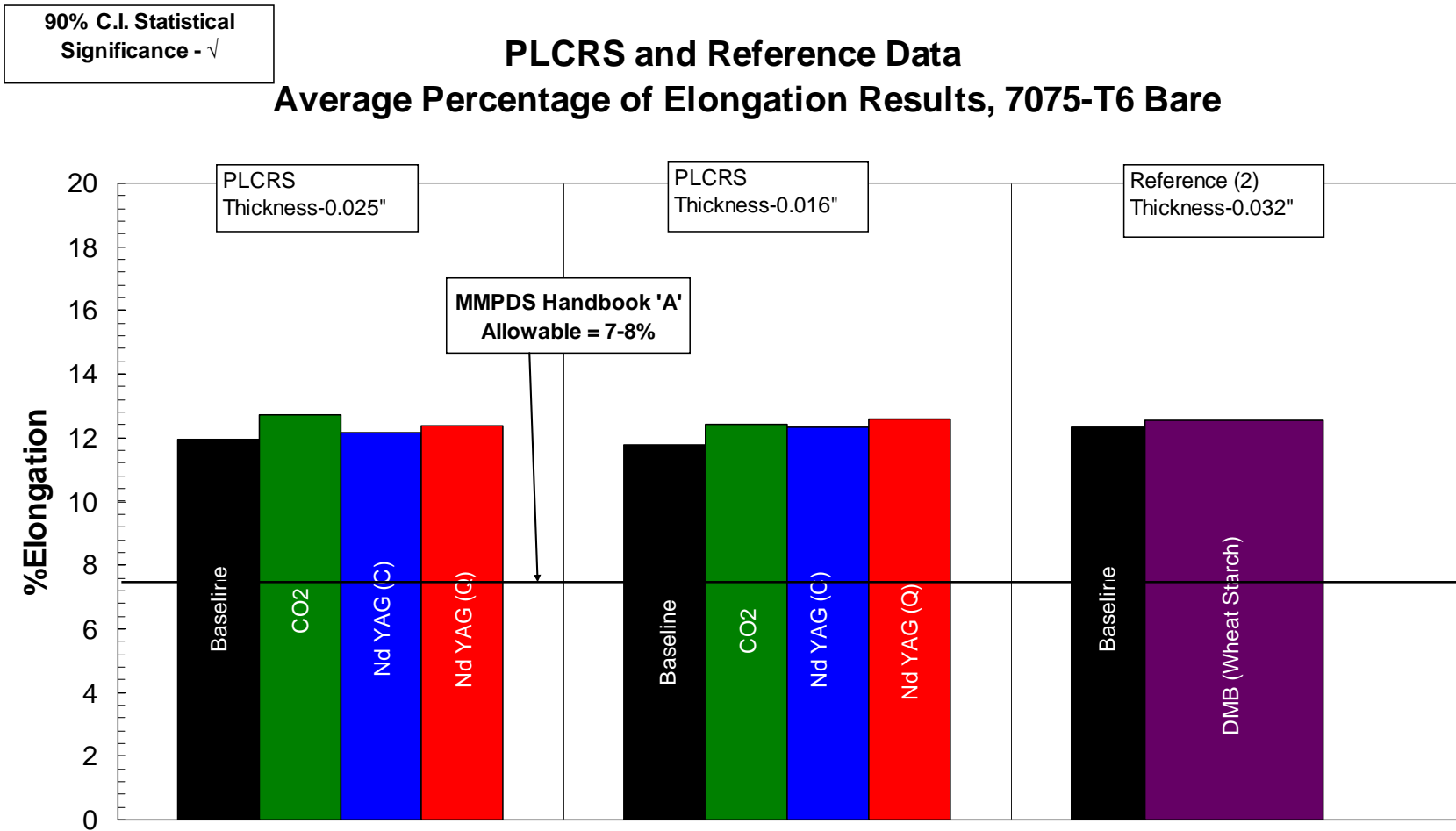
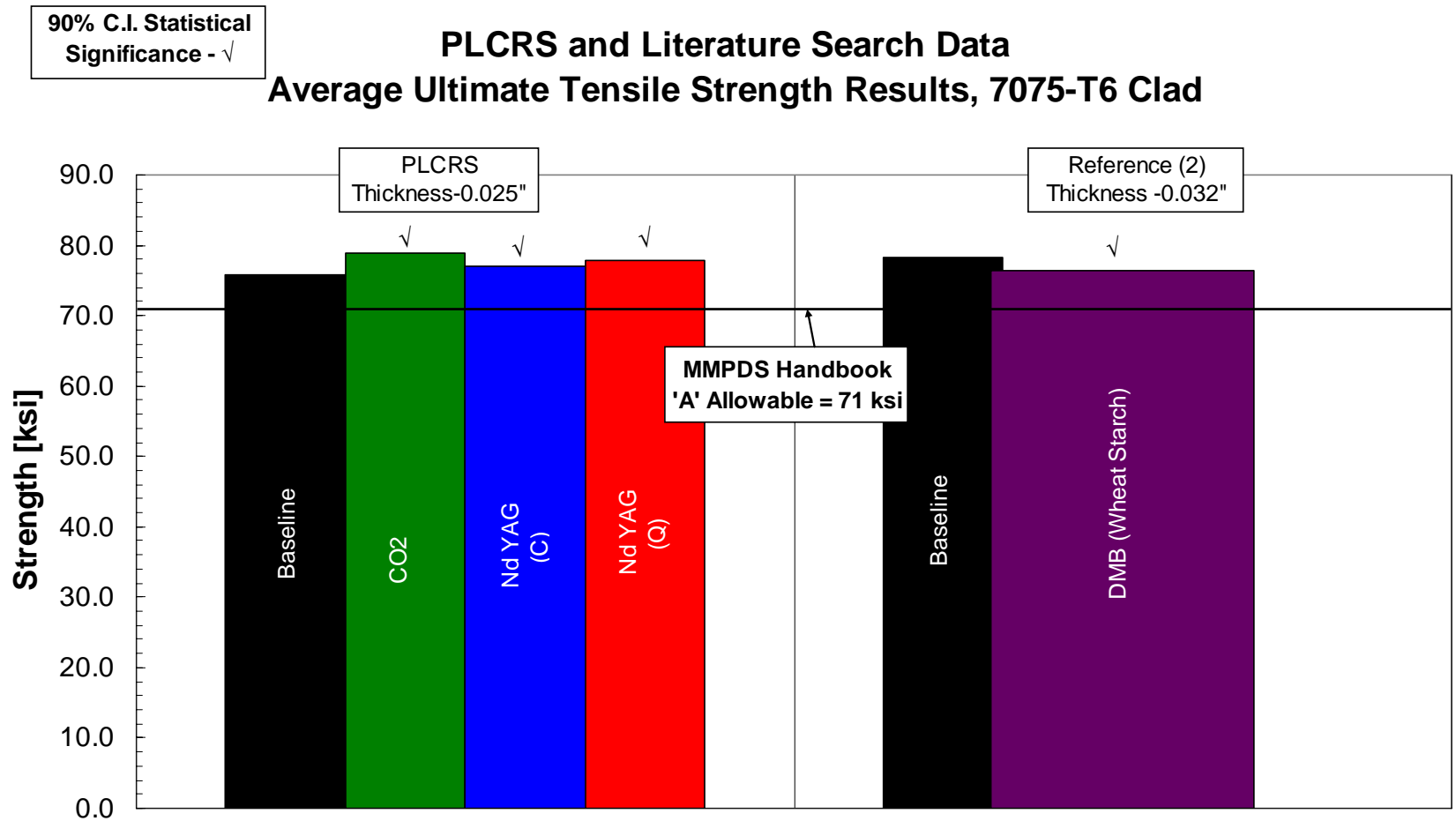


Figure B6. PLCRS and Reference Data Metallic Al7075-T6 Bare Elongation Results.



**Figure B7. PLCRS and Reference Data Metallic Al7075-T6 Clad Ultimate Tensile Strength Results.**

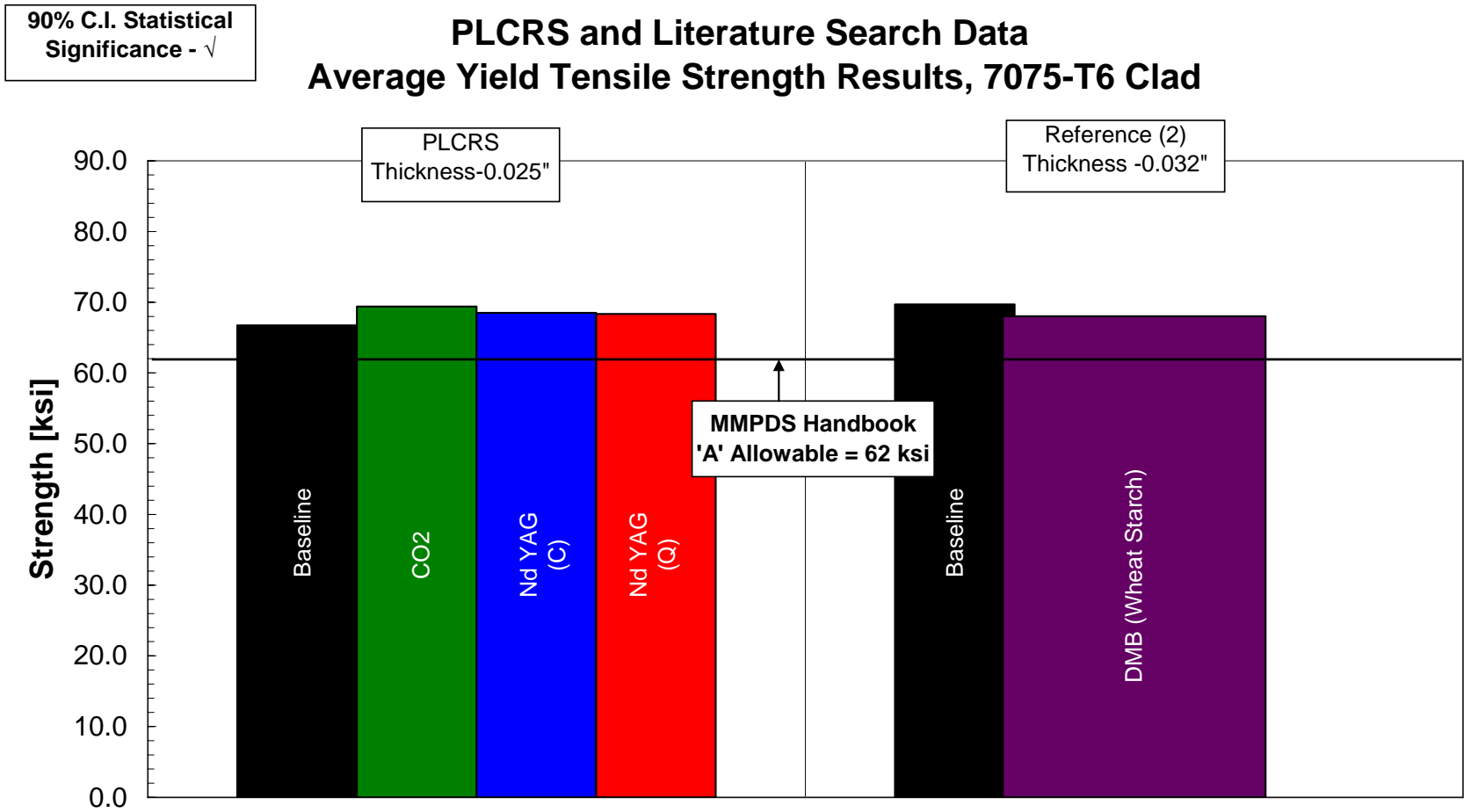


Figure B8. PLCRS and Reference Data Metallic Al7075-T6 Clad Yield Tensile Strength Results.

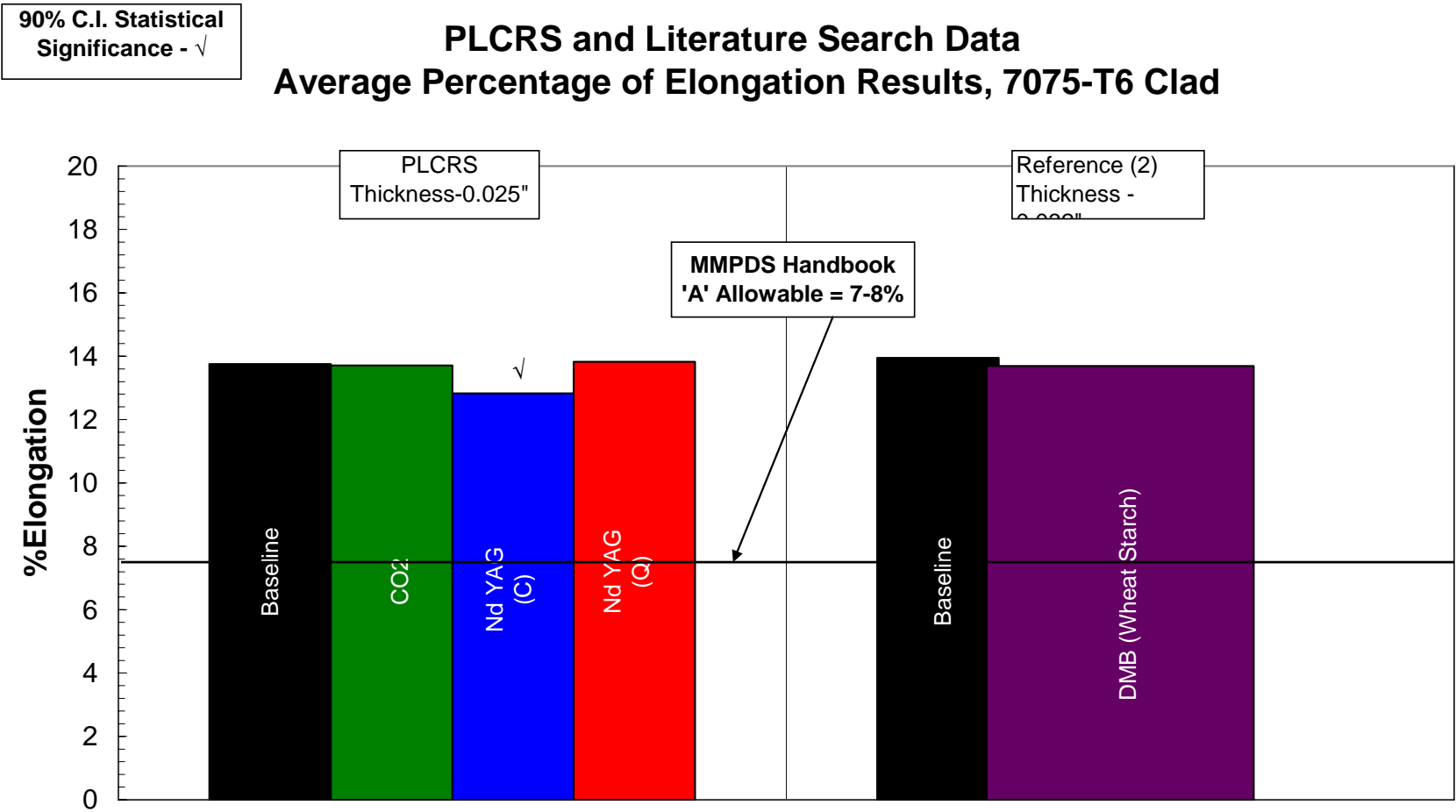


Figure B9. PLCRS and Reference Data Metallic Al7075-T6 Clad Elongation Results.

**Reference Data for Tension Testing**

**Reference (3) - "Mechanical Behavior of Al 2024 Al10y Specimen to Paint Stripping by Laser Radiation and Plasma Etching"**

|                |                | <u>UTS</u> | <u>Std Dev</u> | <u>YTS</u> | <u>Std Dev</u> | <u>%Elog</u> | <u>Std Dev</u> | - Number of sample |
|----------------|----------------|------------|----------------|------------|----------------|--------------|----------------|--------------------|
| Baseline       | Al 2024-T3Bare | 70.05076   |                | 47.86077   |                | 17.68        |                | 5                  |
| TEA-CO2 laser  | Al 2024-T3Bare | 68.8905    |                | 45.54025   |                | 16.4         |                | 5                  |
| CO2 laser      | Al 2024-T3Bare | 68.74547   |                | 45.54025   |                | 13.1         |                | 5                  |
| YAG laser      | Al 2024-T3Bare | 68.96302   |                | 46.84554   |                | 12.85        |                | 5                  |
| Excimer laser  | Al 2024-T3Bare | 68.60044   |                | 46.48296   |                | 11.6         |                | 5                  |
| Plasma etching | Al 2024-T3Bare | 67.15011   |                | 47.9913    |                | 3.08         |                | 5                  |

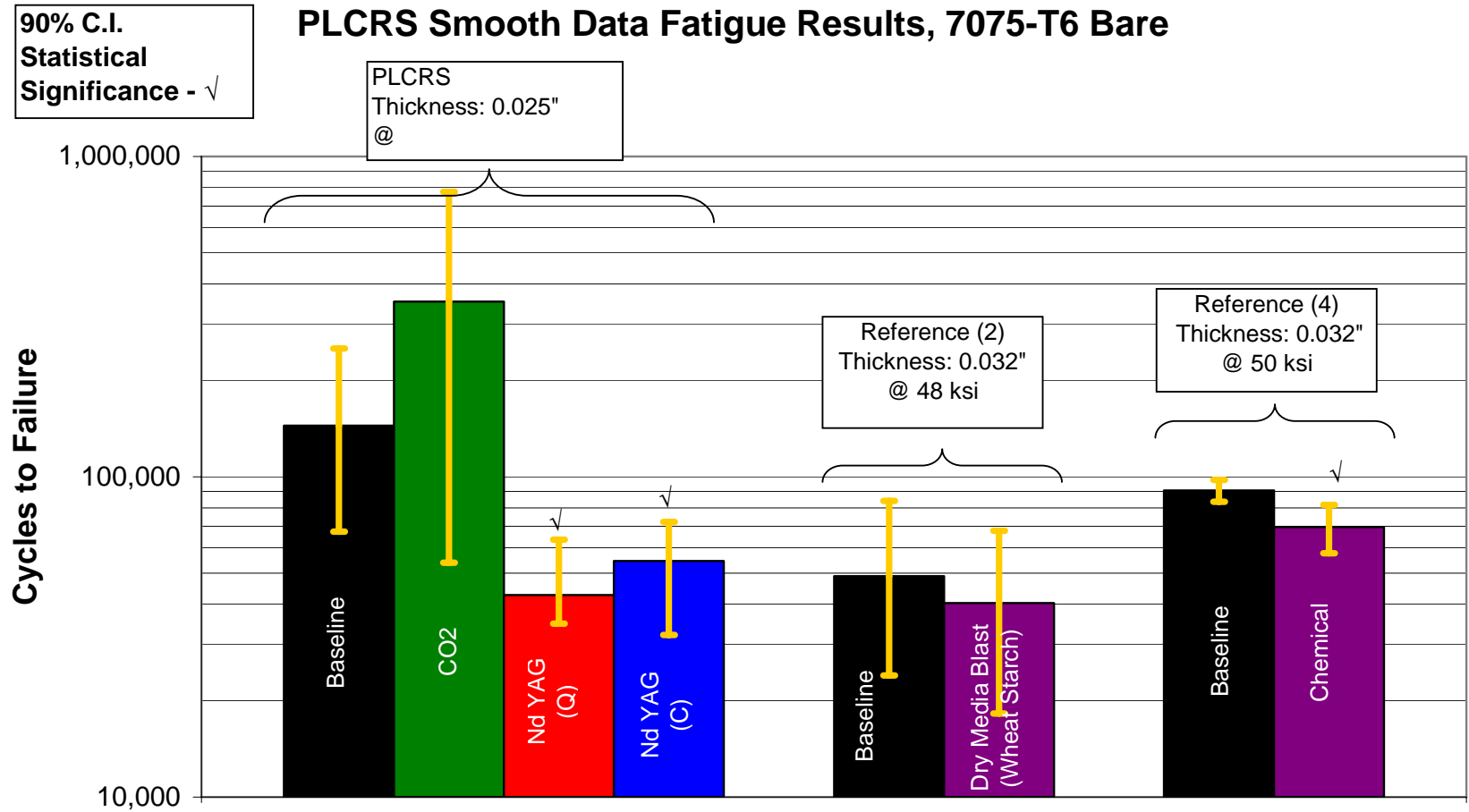
**Reference (2) - "Evaluation of Envirostrip for De-painting Thin-Skinned Aluminum Alloys"**

|             |                | <u>UTS</u> | <u>Std Dev</u> | <u>YTS</u> | <u>Std Dev</u> | <u>%Elog</u> | <u>Std Dev</u> | - Number of sample |
|-------------|----------------|------------|----------------|------------|----------------|--------------|----------------|--------------------|
| Baseline    | Al 2024-T3Bare | 72.83      | 0.1            | 53.94      | 0.24           | 16.93        | 0.44           | 4                  |
| Envirostrip | Al 2024-T3Bare | 72.19      | 0.25           | 52.67      | 0.14           | 18.06        | 0.49           | 4                  |
| Baseline    | Al 2024-T3Clad | 66.91      | 0.38           | 50.48      | 0.39           | 16.70        | 1.00           | 4                  |
| Envirostrip | Al 2024-T3Clad | 65.93      | 0.25           | 48.97      | 0.09           | 16.94        | 0.78           | 4                  |
| Baseline    | Al 7075-T6Bare | 85.41      | 0.37           | 79.32      | 2.23           | 12.33        | 0.75           | 4                  |
| Envirostrip | Al 7075-T6Bare | 83.65      | 0.29           | 76.06      | 0.31           | 12.55        | 0.26           | 4                  |
| Baseline    | Al 7075-T6Clad | 78.28      | 0.4            | 69.68      | 1.11           | 13.95        | 0.64           | 4                  |
| Envirostrip | Al 7075-T6Clad | 76.38      | 0.09           | 68.03      | 0.11           | 13.69        | 0.54           | 4                  |

**Reference (1) - "Laser Paint Stripping"**

|                 |                | <u>UTS</u>      | <u>Std Dev</u>  | <u>YTS</u> | <u>Std Dev</u>  | <u>%Elog</u> | <u>Std Dev</u>  | - Number of sample |  |
|-----------------|----------------|-----------------|-----------------|------------|-----------------|--------------|-----------------|--------------------|--|
| Baseline        | Al 2024-T3Bare | 64960           |                 | 63590      |                 | 16.3         |                 |                    |  |
|                 |                | 64750           |                 | 64400      |                 | 16.7         |                 |                    |  |
|                 |                | 65470           |                 | 64390      |                 | 17           |                 |                    |  |
|                 |                | 65109           |                 | 63520      |                 | 16.4         |                 |                    |  |
|                 |                | 65070           |                 | 65030      |                 | 11.6         |                 |                    |  |
|                 |                | <b>Avg.</b>     | <b>65071.8</b>  |            | <b>64186</b>    |              | <b>15.6</b>     |                    |  |
|                 |                | <b>Std Dev.</b> | <b>262.6808</b> |            | <b>632.163</b>  |              | <b>2.252776</b> |                    |  |
| CO2             | Al 2024-T3Bare | 66980           |                 | 65260      |                 | 15.6         |                 |                    |  |
|                 |                | 65060           |                 | 63450      |                 | 16.1         |                 |                    |  |
|                 |                | 64790           |                 | 62990      |                 | 17.1         |                 |                    |  |
|                 |                | 67330           |                 | 65580      |                 | 16.3         |                 |                    |  |
|                 |                | 65250           |                 | 64210      |                 | 18.6         |                 |                    |  |
|                 |                | 64660           |                 | 63360      |                 | 16.3         |                 |                    |  |
|                 |                | 64540           |                 | 63290      |                 | 15.5         |                 |                    |  |
|                 |                | 66570           |                 | 64480      |                 | 16.2         |                 |                    |  |
|                 |                | 67080           |                 | 65560      |                 | 16.2         |                 |                    |  |
|                 |                | 67330           |                 | 65580      |                 | 16           |                 |                    |  |
|                 |                | <b>Avg.</b>     | <b>65959</b>    |            | <b>64376</b>    |              | <b>16.39</b>    |                    |  |
| <b>Std Dev.</b> | <b>1193.04</b> |                 | <b>1059.929</b> |            | <b>0.890006</b> |              |                 |                    |  |

**APPENDIX C**  
**FATIGUE RESULTS**



**Figure C1. PLCRS and Reference Data 7075-T6 Bare Smooth Fatigue Results.  $\checkmark$  indicates a statistical difference at a 90% simultaneous confidence level.**

90% C.I. Statistical  
Significance -  $\checkmark$

## PLCRS Notch Data Fatigue Results, 7075-T6 Bare

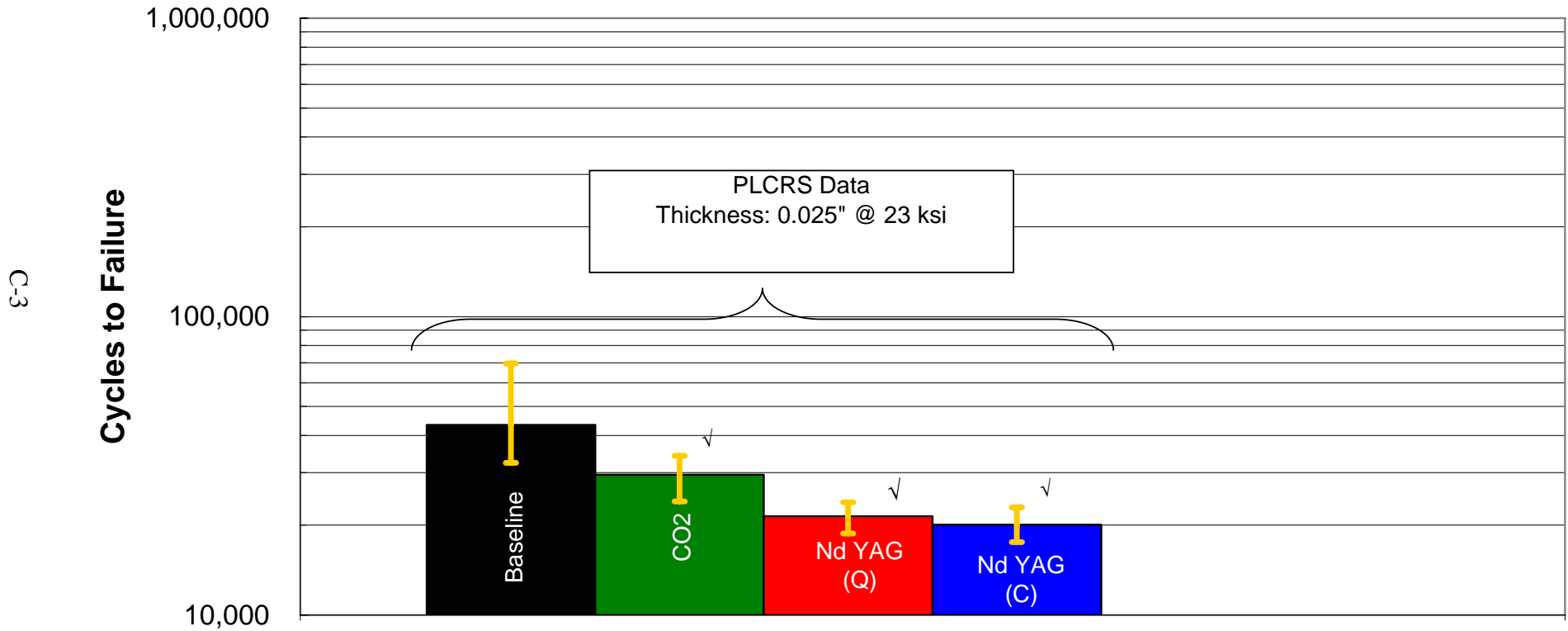


Figure C2. PLCRS and Reference Data Metallic Al7075-T6 Bare Notch Fatigue Results.

## PLCRS Smooth Data Fatigue Results, 7075-T6 Clad

90% C.I. Statistical Significance -  $\sqrt{\quad}$

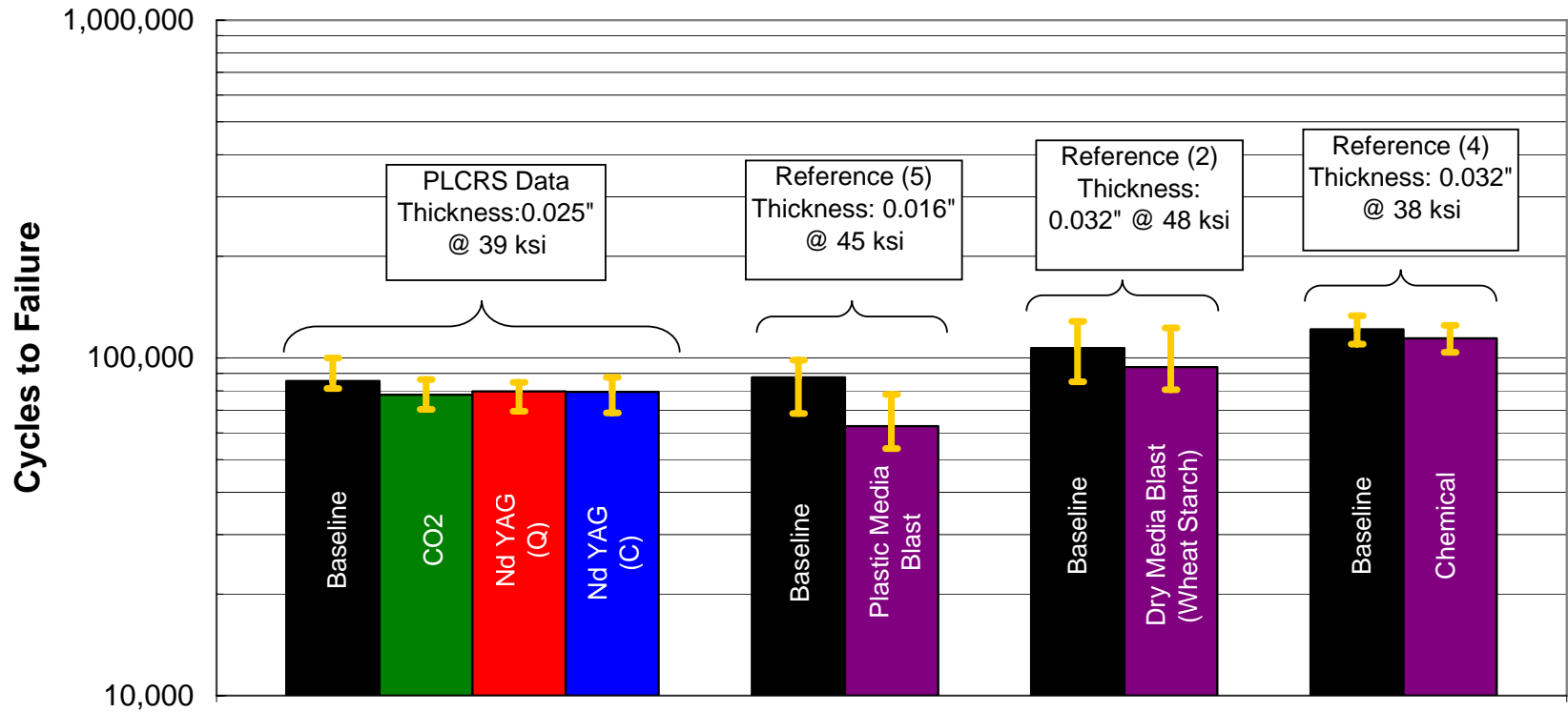


Figure C3. PLCRS and Reference Data Metallic Al7075-T6 Clad Smooth Fatigue Results.

90% C.I. Statistical Significance -  $\sqrt{\quad}$

## PLCRS Notch Data Fatigue Results, 7075-T6 Clad

C-5

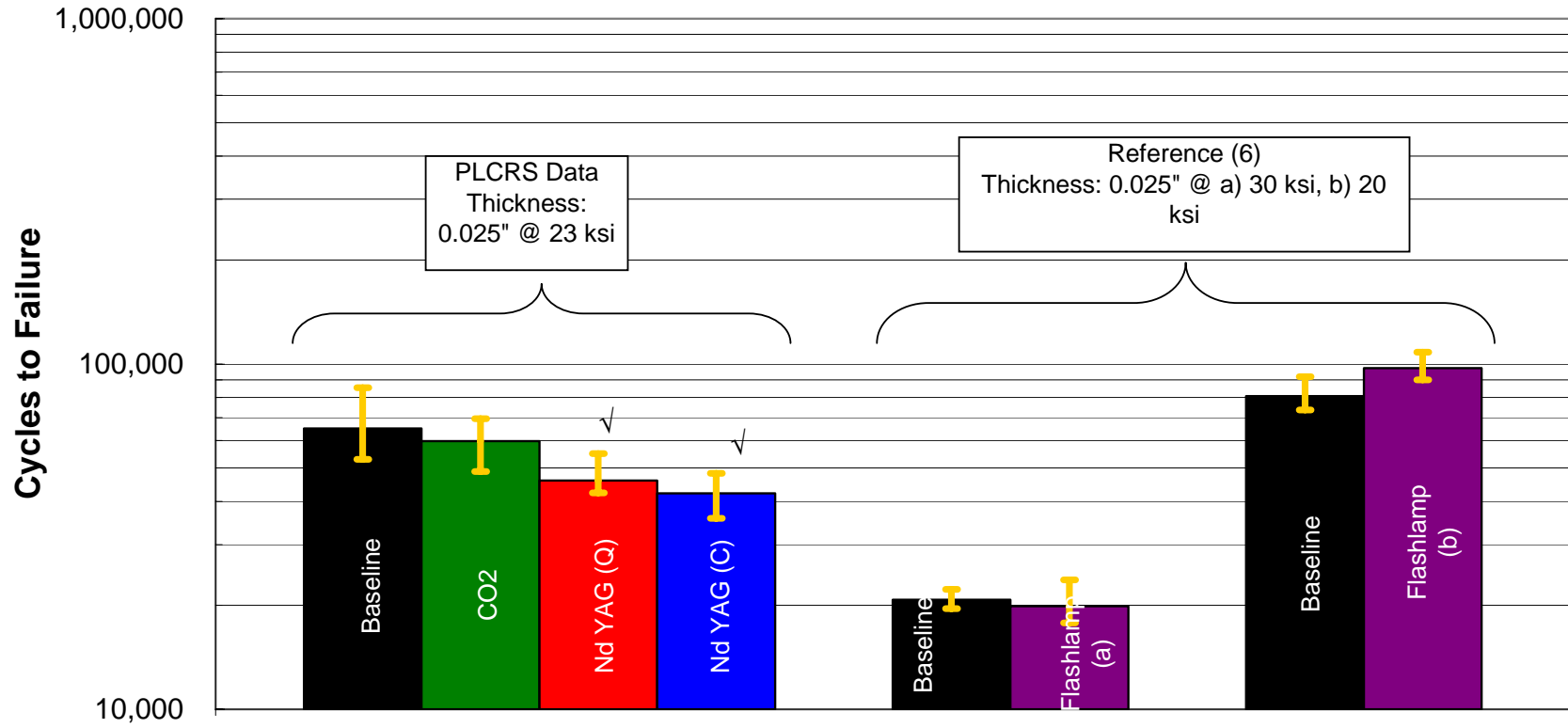


Figure C4. PLCRS and Reference Data Metallic Al7075-T6 Clad Notch Fatigue Results.

**7075-T6 Bare Smooth Fatigue Data**

**Reference (4)**

|          |        | <u>Average</u> |          | N - Number of Samples |
|----------|--------|----------------|----------|-----------------------|
| Control  | 83,588 | 90,680         | 4.957512 | 12                    |
|          | 97,772 |                |          |                       |
| Chemical | 57,671 | 69,656         | 4.842959 | 8                     |
|          | 81,641 |                |          |                       |

**Reference (2)**

|             | <u>Average</u> | <u>Std Dev</u> | <u>Average</u> | <u>Std Dev</u> |    |
|-------------|----------------|----------------|----------------|----------------|----|
| Control     | 48,937         | 17,662         | 4.689637       | 4.24704        | 10 |
| Envirostrip | 40,300         | 17,484         | 4.605305       | 4.242641       | 10 |

## 7075-T6 Clad Fatigue Data

### Smooth

#### Reference (5)

|         |        |        |          |
|---------|--------|--------|----------|
| Control | 68,500 | 87,667 | 4.942834 |
|         | 96,000 |        |          |
|         | 98,500 |        |          |
| PMB     | 78,000 | 62,867 | 4.79842  |
|         | 56,700 |        |          |
|         | 53,900 |        |          |

#### Reference (2)

|         | <u>Average</u> | <u>Std Dev</u> | <u>Average</u> | <u>Std Dev</u> | N - Number of Samples |
|---------|----------------|----------------|----------------|----------------|-----------------------|
| Control | 106,900        | 13,762         | 5.028978       | 4.138682       | 10                    |
| Blasted | 93,852         | 14,361         | 4.972444       | 4.157185       | 10                    |

#### Reference (4)

|          |         |        |          | N - Number of Samples |
|----------|---------|--------|----------|-----------------------|
| Control  | 109,903 | 121525 | 5.084666 | 12                    |
|          | 133,147 |        |          |                       |
| Chemical | 103,928 | 114400 | 5.058426 | 8                     |
|          | 124,872 |        |          |                       |

### Notch

#### Reference (6)

|                   |         |        |          |
|-------------------|---------|--------|----------|
| Control (30 ksi)  | 20,614  | 20,770 | 4.317436 |
|                   | 19,573  |        |          |
|                   | 20,639  |        |          |
|                   | 22,254  |        |          |
| Stripped (30 ksi) | 17,811  | 19,918 | 4.299246 |
|                   | 20,000  |        |          |
|                   | 18,134  |        |          |
|                   | 23,727  |        |          |
| Control (20 ksi)  | 91,787  | 80,779 | 4.9073   |
|                   | 78,845  |        |          |
|                   | 78,900  |        |          |
|                   | 73,585  |        |          |
| Stripped (20 ksi) | 82,389  | 97,247 | 4.987874 |
|                   | 116,427 |        |          |
|                   | 79,536  |        |          |
|                   | 110,634 |        |          |

C-7

## 2024-T3 Clad Fatigue Data

### Smooth and Notch

#### Reference (5)

|         |         |        |          |
|---------|---------|--------|----------|
| Control | 67,237  |        |          |
|         | 74,111  |        |          |
|         | 101,700 |        |          |
|         | 76,676  |        |          |
|         | 83,929  |        |          |
|         | 94,228  |        |          |
|         | 87,327  |        |          |
|         | 100,758 |        |          |
|         | 77,394  |        |          |
|         | 93,755  | 86,518 | 4.937104 |

#### Reference (2)

|         | <u>Cycles</u> | <u>Std Dev</u> | <u>Cycles</u> | <u>Std Dev</u> | N - Number of Samples |
|---------|---------------|----------------|---------------|----------------|-----------------------|
| Control | 100157        | 10494          | 5.000681      | 4.02094106     | 10                    |
| Blast   | 66500         | 11281          | 4.822822      | 4.052347599    | 10                    |

#### Reference (4)

|          |         |        |          | N - Number of Samples |
|----------|---------|--------|----------|-----------------------|
| Control  | 112,854 |        |          |                       |
|          | 121,860 | 117357 | 5.069509 | 12                    |
| Chemical | 82,601  |        |          |                       |
|          | 104,007 | 93304  | 4.9699   | 8                     |

#### Reference (6)

|     |        |        |          |
|-----|--------|--------|----------|
| PMB | 36,584 |        |          |
|     | 67,527 |        |          |
|     | 80,355 |        |          |
|     | 77,450 |        |          |
|     | 45     |        |          |
|     | 27,665 |        |          |
|     | 49,075 |        |          |
|     | 72,499 |        |          |
|     | 91,650 |        |          |
|     | 61,220 | 56,407 | 4.751333 |

|                   |         |         |         |  |
|-------------------|---------|---------|---------|--|
|                   |         |         |         |  |
| Control (30 ksi)  |         |         |         |  |
|                   | 39,929  |         |         |  |
|                   | 30,408  |         |         |  |
|                   | 27,608  |         |         |  |
|                   | 23,025  | 30,243  | 4.48062 |  |
|                   | 24,666  |         |         |  |
| Stripped (30 ksi) |         |         |         |  |
|                   | 30,615  |         |         |  |
|                   | 44,508  |         |         |  |
|                   | 28,100  | 31,972  | 4.50477 |  |
|                   | 126,649 |         |         |  |
| Control (20 ksi)  |         |         |         |  |
|                   | 173,515 |         |         |  |
|                   | 163,970 |         |         |  |
|                   | 147,424 | 152,890 | 5.18438 |  |
|                   | 141,938 |         |         |  |
| Stripped (20 ksi) |         |         |         |  |
|                   | 168,236 |         |         |  |
|                   | 153,498 |         |         |  |
|                   | 143,788 | 151,865 | 5.18146 |  |

|     |        |  |  |
|-----|--------|--|--|
| PMB | 82,998 |  |  |
|     | 76,923 |  |  |
|     | 84,479 |  |  |
|     | 69,337 |  |  |
|     | 94,511 |  |  |
|     | 50,500 |  |  |
|     | 71,024 |  |  |
|     | 68,562 |  |  |
|     | 88,300 |  |  |

C-8

**APPENDIX D**

**FATIGUE CRACK GROWTH RATE RESULTS**

# PLCRS Fatigue Crack Growth Rate Results, 7075-T6 clad (0.025") Paint System #05

(Mil-PRF-23377 primer/PRF-85285 topcoat) unless noted

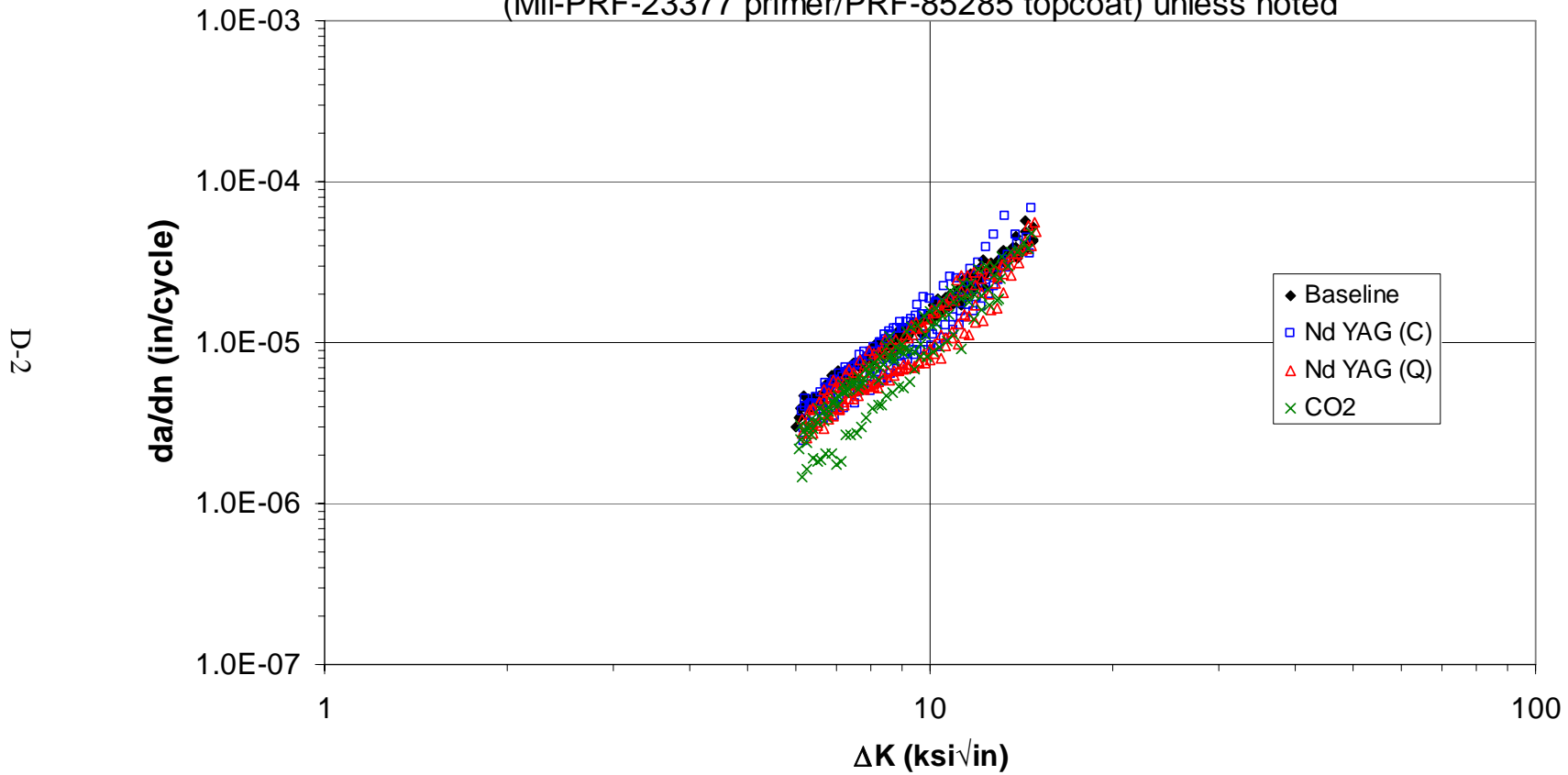
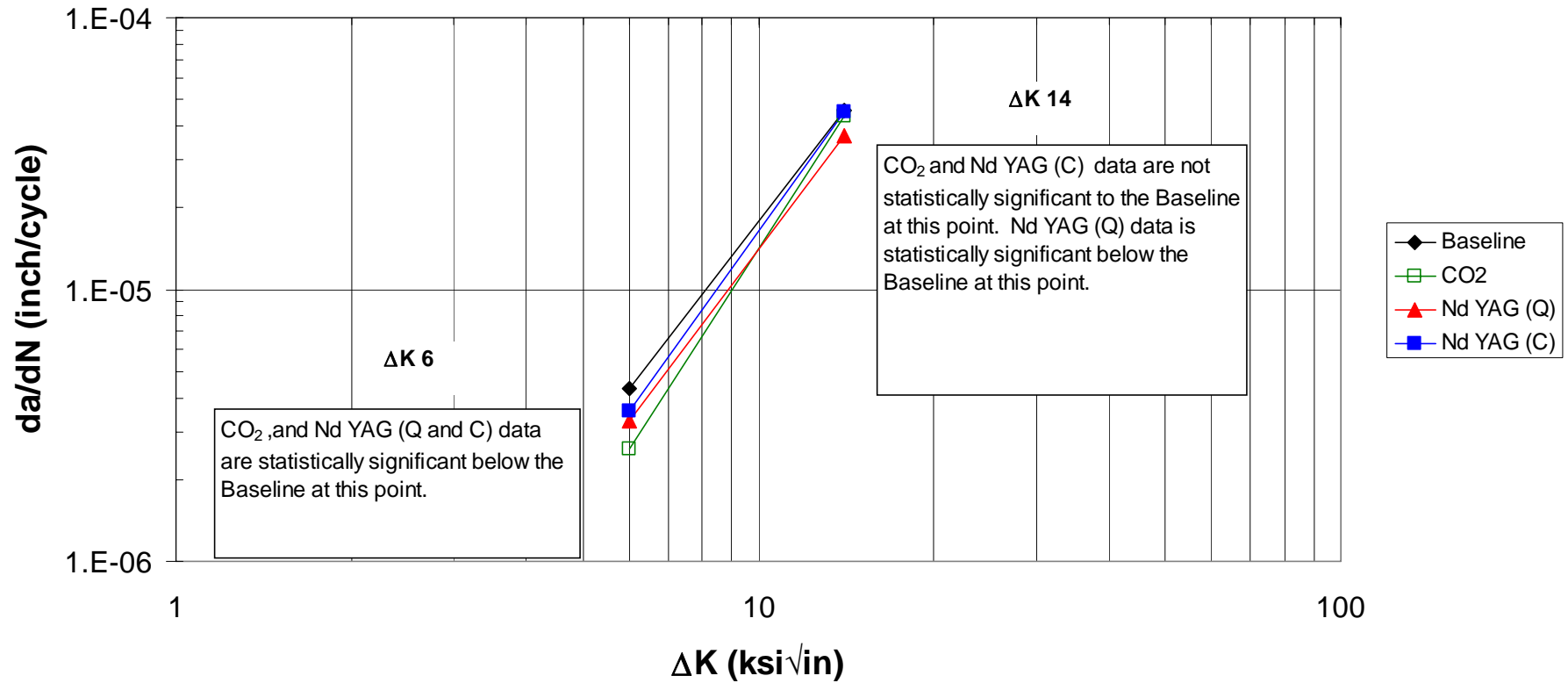


Figure D1. PLCRS Fatigue Crack Growth Rate Metallic Al7075-T6 Clad Results.

**PLCRS Fatigue Crack Growth Rate Results, 7075-T6 Clad (0.025")**  
**Paint System #05**  
(Mil-PRF-23377 primer/PRF-85285 topcoat) unless noted

D-3

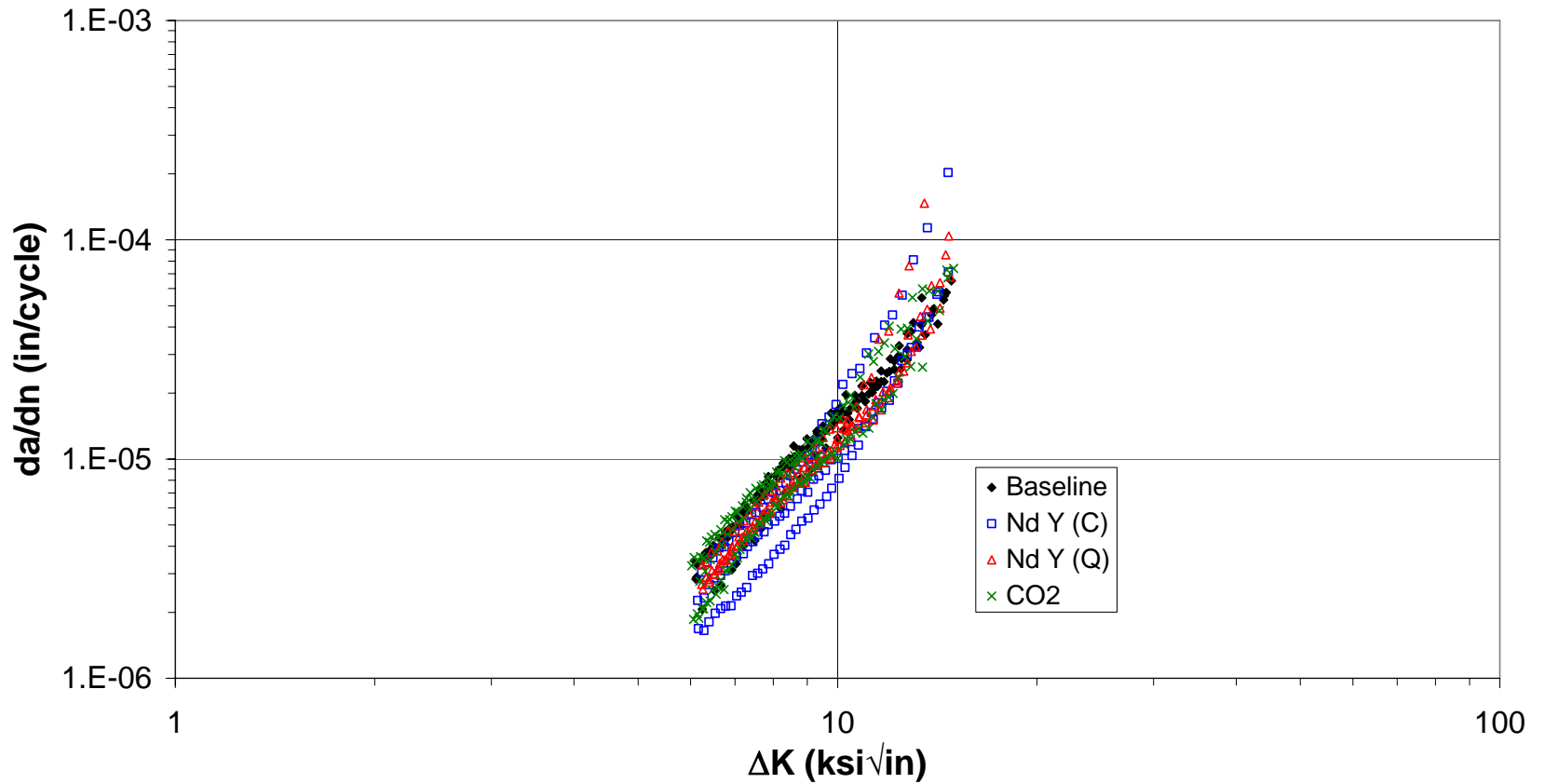


**Figure D2. Metallic Al 7075-T6 Clad Fatigue Crack Growth Rate Statistical Analysis at ΔK of 6 and 14.**

# PLCRS Fatigue Crack Growth Rate Results, 7075-T6 bare (0.016")

## Paint System #05

(Mil-PRF-23377 primer/PRF-85285 topcoat) unless noted



D-4

Figure D3. PLCRS Fatigue Crack Growth Rate Metallic Al7075-T6 Bare Results.

# PLCRS Fatigue Crack Growth Rate Results, 7075-T6 Bare (0.025")

## Paint System #05

(Mil-PRF-23377 primer/PRF-85285 topcoat) unless noted

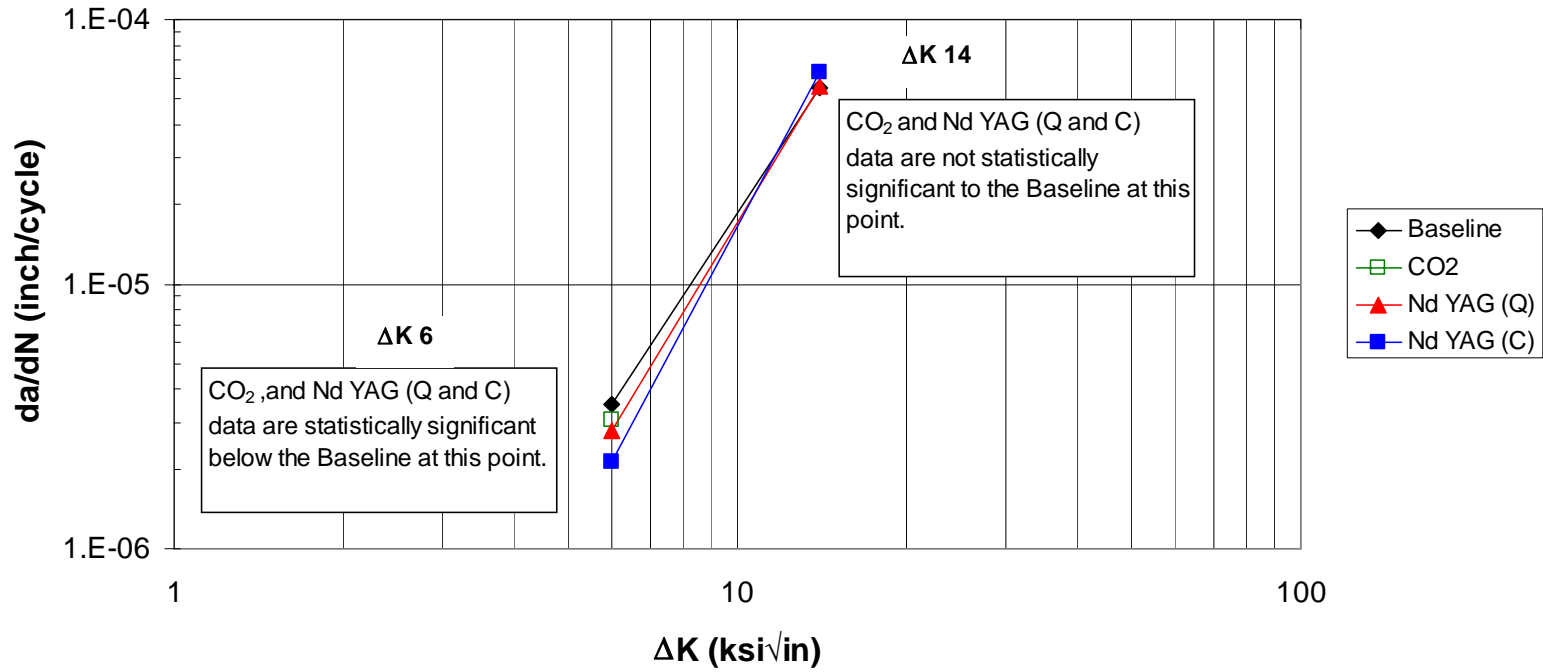


Figure D4. Metallic Al 7075-T6 Bare Fatigue Crack Growth Rate Statistical Analysis at ΔK of 6 and 14.

**APPENDIX E**  
**FLEXURAL STRENGTH RESULTS**

90% C.I. Statistical Significance - ✓

### PLCRS Flexural Strength Results

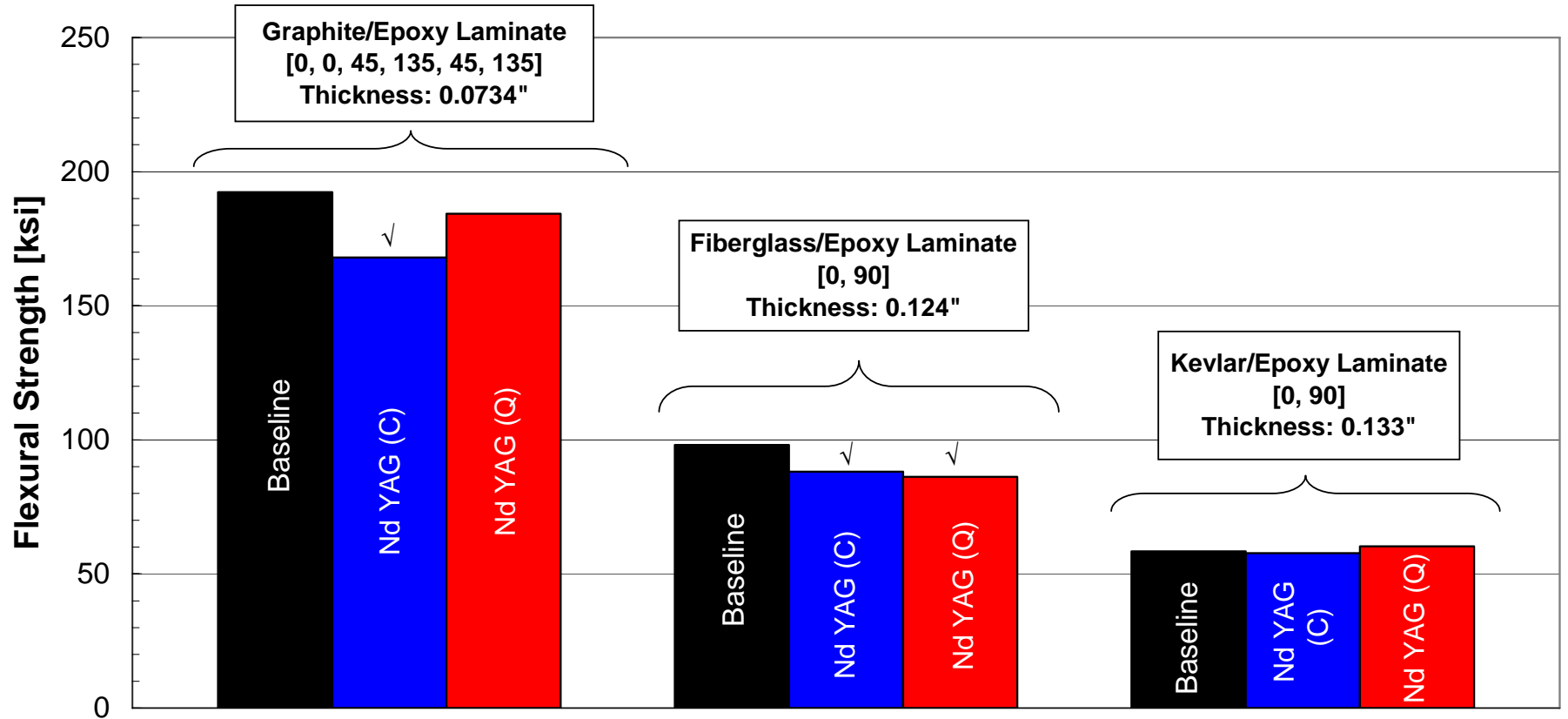


Figure E1. PLCRS Flexural Strength Results.

90% C.I. Statistical Significance -  $\checkmark$

### PLCRS and Reference Data Flexural Strength Results, Graphite/Epoxy Laminate (Compression)

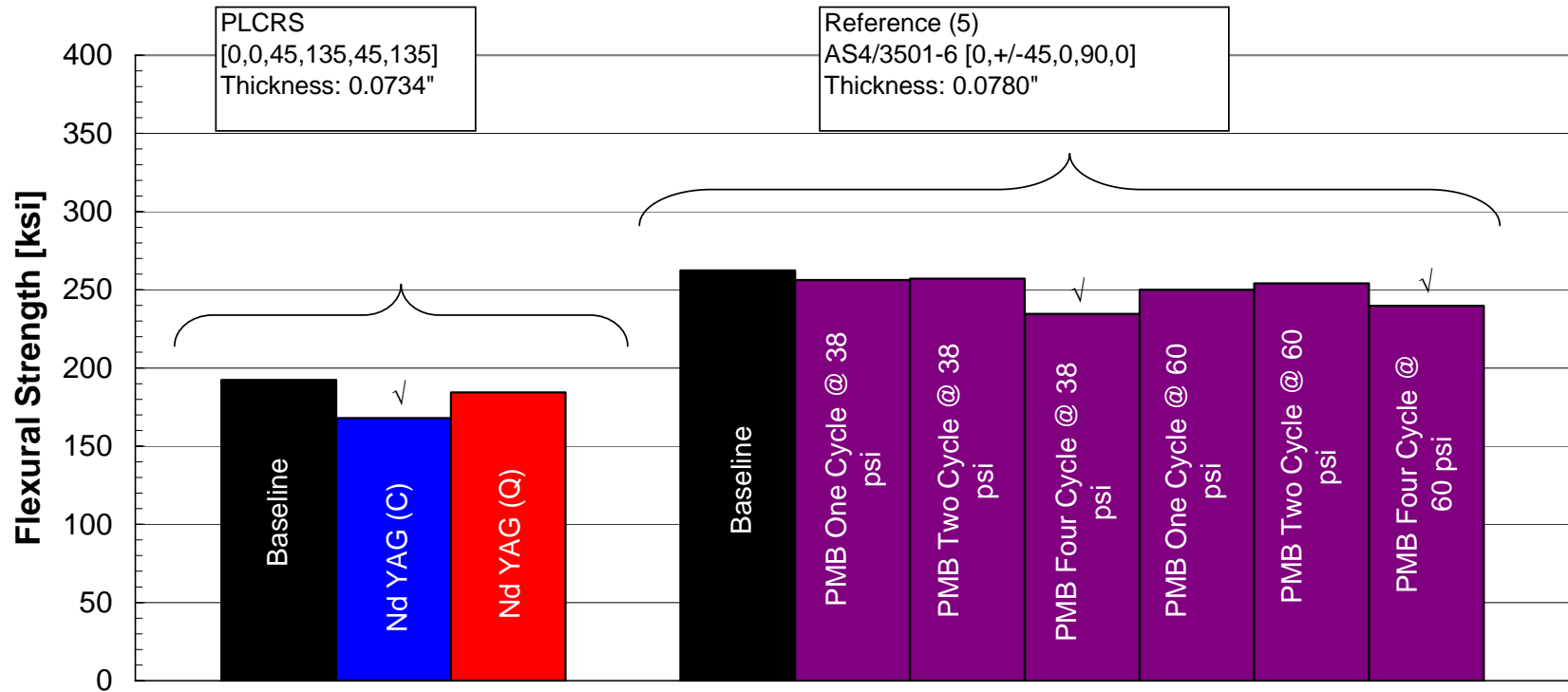


Figure E2. PLCRS and Reference Data Flexural Strength Results.

## Reference Data for Flexural Strength

### Reference (7)

| <b>Wet Abrasive</b> |   | Average Flexural Strength |
|---------------------|---|---------------------------|
| Baseline            | - | 140.4                     |
| Substrate           | - | 156.3                     |

| <b>Bicarbonate</b> |   | Average Flexural Strength |
|--------------------|---|---------------------------|
| Baseline           | - | 150.1                     |
| Substrate          | - | 171.4                     |

| <b>Abrasive</b> |   | Average Flexural Strength |
|-----------------|---|---------------------------|
| Baseline        | - | 143.7                     |
| Substrate       | - | 146.4                     |

### Reference (5)

#### PMB

|           | Number of Specimen | Average Strength | Std. Dev. |
|-----------|--------------------|------------------|-----------|
| Baseline  | 7                  | 161.78           | 6.87      |
| One @ 38  | 8                  | 157.15           | 17.74     |
| One @ 38  | 6                  | 146.67           | 13.37     |
| Two @ 38  | 9                  | 149.60           | 12.47     |
| Four @ 38 | 10                 | 158.49           | 15.39     |
| One @ 60  | 8                  | 153.91           | 14.62     |
| Two @ 60  | 9                  | 144.45           | 11.37     |
| Four @ 60 | 7                  | 142.68           | 9.70      |

### Reference (9)

#### Flash lamp

|           | Number of Specimen | Average Strength | Std. Dev. |
|-----------|--------------------|------------------|-----------|
| Baseline  | 12                 | 221.1            | 8.0       |
| Substrate | 12                 | 210.2            | 8.0       |