THE EFFECTS OF SEAM DESIGN ON AIRBAG INDUCED SKIN ABRASIONS FROM HIGH-RATE SHEAR LOADING

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ABSTRACT

Approximately 66% of all airbag deployments in the United States result in at least one skin injury, with 47% of these skin injuries attributed directly to the airbag deployment. In order to reduce this injury risk, the purpose of the study was to evaluate risk of skin abrasions from various airbag seam designs using a new shear methodology. The high-rate shear loading was performed with pneumatic impactor that propelled a section of airbag fabric across porcine skin at 85 m/s in order to simulate the interaction of the seam across the forearm during an airbag deployment. A total of 27 tests (3 control and 24 with fabric) were performed with 8 different seam designs. A 40 cm by 10 cm section of airbag fabric with each seam was forced across a 5 cm by 5 cm of porcine skin that was acquired within two hours post-mortem. A new skin injury scaling system, the total abrasion score, was created that quantifies the relative volume of skin removed by using cross-section histology slides to examine the depth and width of the abrasion for the entire sample. No abrasions were observed in the 3 control tests, but abrasions were observed in all 24 of the tests with airbag fabric. The abrasions ranged from minor removal of epidermal tissue to more severe abrasions into the subcutaneous level. The photographic images indicated that the tissue transfer occurred primarily on the seam portion of the fabric samples. Statistical analysis revealed that the unturned sewn seam orientation resulted in significantly more severe abrasions than the woven unturned seam orientation ($p = 0.01$). In addition, this system and results illustrate that shear loading should be considered in addition to normal loading, and that severe abrasions can be caused by normal pressures well below the 1.75 MPa injury threshold previously published.

Keywords: Airbags, Arms, Face, Injury Criteria, Shear

ALTHOUGH AIRBAGS have been shown to reduce the incidence of life threatening injuries, they have increased the risk of minor injuries such as those to the skin (Dalmotas 1995, Foley 2000, Foley, 1995). A study of the National Automobile Sampling System (NASS) found that 66% of front seat occupants exposed to an airbag deployment incur a skin injury, 47 % of these injuries are attributed directly to the airbag itself (Jernigan 2001). Of these injuries, 42% occur to the upper extremities, 41% occur to the face, 3% occur to the neck, 11% occur to the chest and abdomen and 2% occur to the lower extremities (Figure 1). There has also been numerous case studies indicating airbag interaction as the source of skin injuries to the upper extremities (Freedman 1995, Huelke 1995, Burton 1994, Molia 1996), face (Cocke 2002, Duma 2000, Duma, 1996, Murphy 2000, Rozner 1996, Smally 1992, Smock 1995), neck (Hansen 1999, Morrison 1998, Steinmann 1992), chest and abdomen (Beckerman 1995), and lower extremities (Weinman 1995). While these skin injuries may not be life threatening, nearly 300,000 occupants incur an airbag induced skin injury every year in the United States alone. Because this number is so large, there is considerable motivation for investigating the possibility of airbag cushion modifications that may reduce the risk of skin injury.

In order to investigate facial lacerations from contact with the windshield, the Triplex Laceration Index (TLI) was developed (Pickard, 1973). This allowed for the measurement of skin injuries from sharp edges using chamois leathers. Subsequent research into facial lacerations utilized the TLI as a measure in lacerations in various skin samples (Carelsess, 1982). While TLI is ideal for investigating laceration type injuries from sharp edges, a different mechanism for evaluating broader skin injuries such as abrasions in needed.

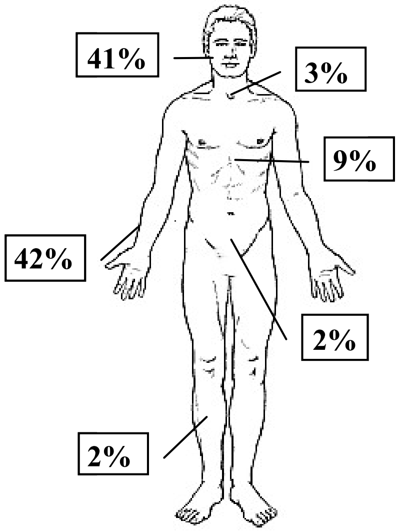


Figure 1: Location of airbag induced skin injuries in frontal crashes from NASS cases for the years 1993 through 2000 (Jernigan, 2001).

Early airbag abrasion research done by Kikuch showed that injury severity is directly proportional to the total pressure exerted onto the skin by an airbag (Kikuch 1975). This was found by deploying airbags onto the shaved regions of rabbit heads; however, no specific injury criterion was recommended. Reed performed studies on human volunteers to elucidate the potential for skin abrasion caused by airbag deployment (Reed 1992). The volunteers exposed the front of their lower leg to a deploying airbag. The magnitude of the pressure exerted onto the volunteers by the airbag was determined using an instrumented leg-form placed in the same position as the volunteer's leg to insure they would be exposed to similar pressures. The response time of the load cells used on the instrumented leg form were too slow to capture the event; therefore, Reed utilized Fuji pressure film to record the resulting pressure. Reed concluded that normal loading alone, as measured by the pressure film, induced enough pressure to cause skin abrasions. Two forms of skin abrasion tolerance levels were presented: peak pressure from the Fuji film of 1.75 MPa (2490 psi), or a peak leading edge airbag velocity of 85 m/s (190 mph). Reed also established a method for utilizing these injury criteria by placing Fuji Pressure Film on the surface of a PVC pipe that was exposed to an airbag deployment in a test configuration that assumed a normal loading injury mechanism (Reed 1993). Suigmoto utilized a similar test configuration, but recommended a slightly lower peak velocity criterion at 70 m/s (157 mph) (Suigmoto 1994).

While previous work by Reed presents a well developed injury criterion for normal pressure alone, it does not characterize all types of airbag loading. In particular, the type of loading that would occur in the region of the airbag seam should be tested and evaluated. It is suggested that there are two general injury mechanisms for airbag induced skin injuries: normal pressure from perpendicular contact of the airbag with the face and thoracic areas, and shear loading as the airbag expands and interacts with the upper extremities (Figure 2). Given that the upper extremity is the region with the highest incidence of airbag induced skin abrasions, and the location of the airbag seam during deployment, this study develops a method for evaluating airbag induced skin abrasions from high-rate shear loading. The specific purpose of this study is to evaluate the risk of skin abrasions from various airbag seam designs using a new shear methodology.

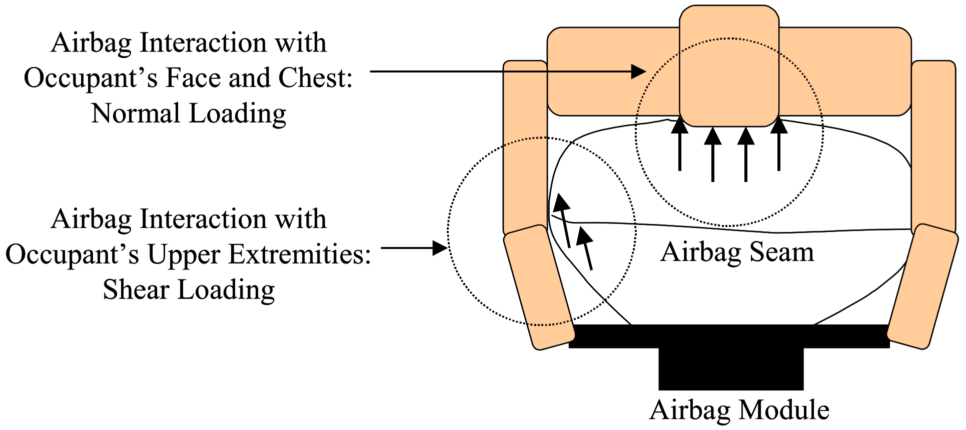


Figure 2: Two proposed injury mechanisms for airbag induced skin abrasions: normal loading of the face and chest versus shear loading of the upper extremities.

METHODS

The high-rate shear loading was performed with a system that propelled a section of airbag fabric across porcine skin in order to simulate the interaction of the seam across the forearm in an airbag deployment (Figure 3). A pneumatic cannon propelled a 2.75 kg impactor mass that provided a step velocity to the fabric by impacting the airbag fabric mount (Figure 4). The airbag fabric mount then translated across the skin mount assembly, which was mounted on linear bearings that allowed it to translate and absorb the energy of the impacting mass. The skin mount assembly allowed for the application of an initial normal load to be applied to the skin. Just prior to testing the skin was lowered and allowed to rest on the fabric mount.

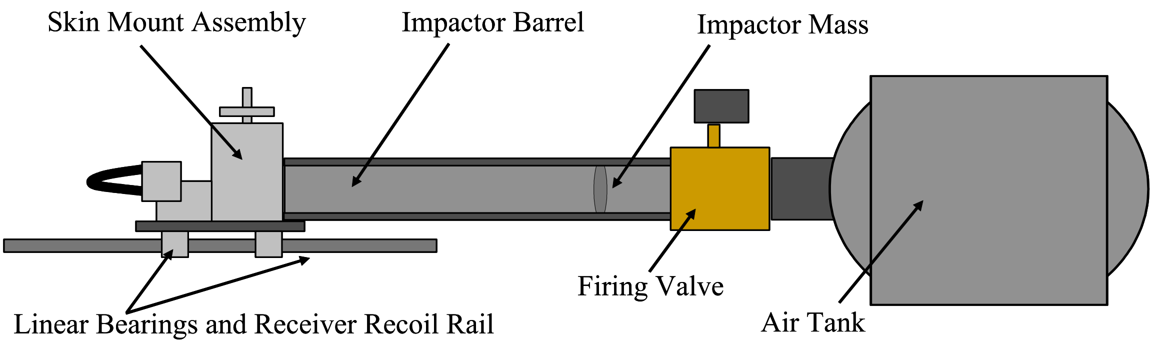


Figure 3: Pneumatic cannon used to achieve the desired velocity between the skin and airbag fabric.

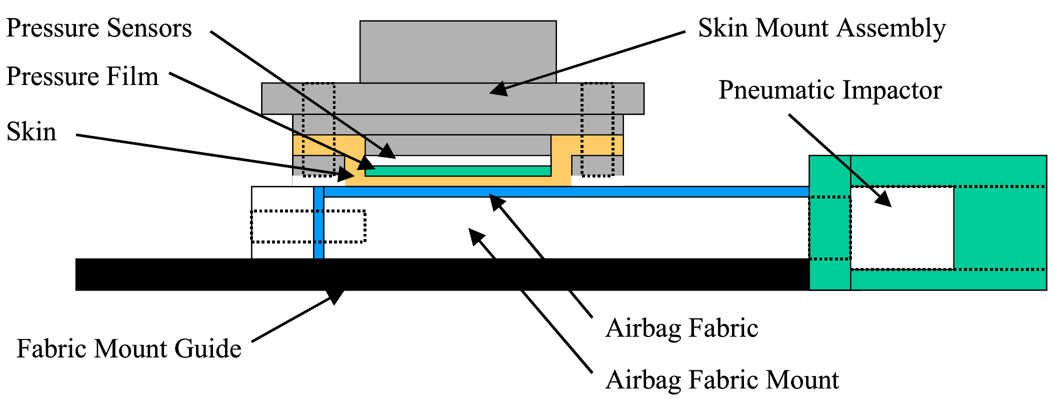


Figure 4: Cross-sectional diagram of the skin mount assembly illustrating the location of the porcine skin and airbag material for abrasion testing.

Previous research done by Reed found that airbag velocities above 85 m/s (190 mph) resulted in skin abrasions for normal loading (Reed 1992). Based on this criterion, the target fabric velocity for the current study was established at approximately 89 m/s (200 mph). The experimental setup was designed to accelerate the airbag fabric to this velocity as it passed below a tissue sample. It should be noted that in real world airbag deployments, the relative velocity of the airbag fabric contacting the skin on the face or upper extremity is a very complex issue that includes other factors not examined in this study such as occupant position, airbag deployment pattern, and inflator type just to name a few.

The skin mount assembly held the skin in place and contained instrumentation that allowed for contact pressure measurements (Figure 5). Before the skin tissue was removed from the porcine subjects, square outlines were made on the skin with the inside dimensions of the clamping bracket. This made it possible to apply pretension to the skin back into its original biaxial state of stress once inside the aluminum bracket (Figure 5a). Once the tissue was secured in the aluminum bracket, the assembly was mounted to the tissue stage (Figure 5b). The tissue stage was prepared with Fuji Film sheets (Medium Fujifilm Prescale Mono Sheet Type, Fuji Photo Film, Tokyo, Japan) and Flexi-Force pressure sensors (FlexiForce A101 100lb, Tekscan, South Boston, MA). A total of four sensors were used, each with a sensing diameter of 9.5 mm. Data acquisition and high speed video was used to capture the event. The data acquisition system was configured to record the pressure exerted on the skin by the airbag seam from the active pressure sensors and sampled at a rate of 28.4 kHz. High-speed digital video (Phantom IV, Vision Research, Wayne, NJ) was used to capture the motion of the fabric mount at 7,100 frames per second. This frame rate allowed sufficient resolution of the fabric block in motion to facilitate velocity calculations for the fabric relative to the skin.

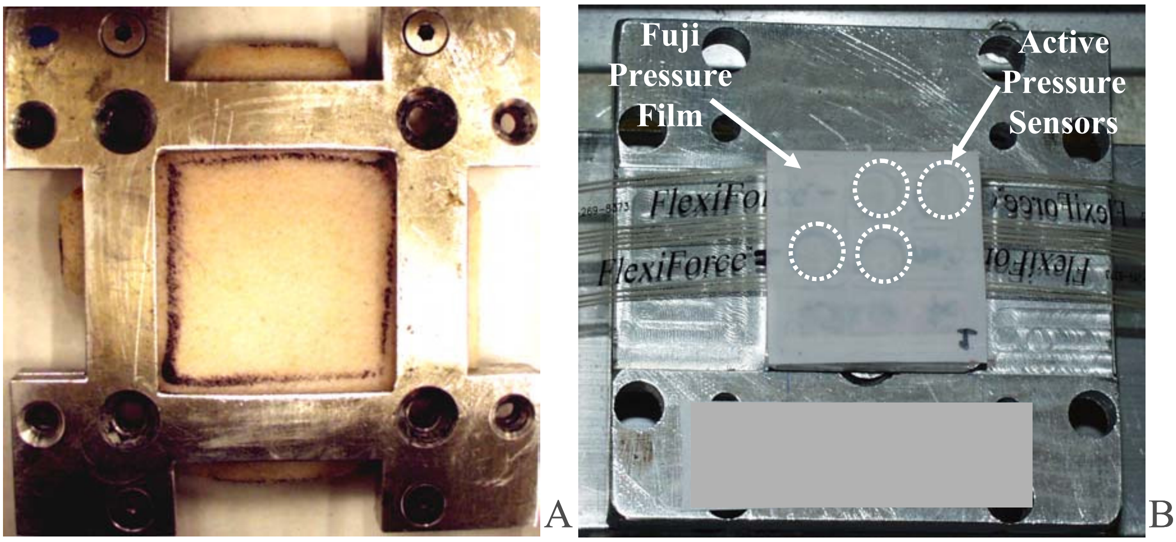


Figure 5: a) Skin mount assembly with tissue in place. b) Tissue stage with sensors installed.

Porcine skin tissues from the lateral sides of two-month old Yorkshires were used due to their similarity to human skin and scheduled availability. A comparative study was performed between human cadaveric tissues and the porcine specimens in order to verify their similarities. Skin samples were taken from the forehead, chest, and upper extremity of two human cadavers and from seven anatomical regions of two porcine subjects. Cross-section histological slides were developed for each sample and compared using a light microscope. In particular, this analysis showed that the thicknesses of the epithelial and dermal layers were nearly identical between the human and porcine samples.

A total of 27 tests (3 control and 24 with fabric) were performed with 8 different seam designs (Table 1). The three control tests were performed with only the polycarbonate block translating over the skin samples. These tests allowed for verification that the test apparatus itself was not inducing skin abrasions. For each of the 24 tests with fabric, a 40 cm by 10 cm section of airbag fabric (Figure 6) with each seam type was forced across a 5 cm by 5 cm of porcine skin that was acquired within two hours post-mortem. The turned seam condition is one in which the airbag has been turned inside out so that the occupant is not exposed to the side of the seam were the two pieces of fabric come together. The unturned represents the opposite case in which the occupant would be exposed to the stitching used to hold the fabric ends together. The no buckle configurations were performed by removing the seam and securing it vertically in the polycarbonate fabric mount. For the parallel case the seam was mounted parallel to the motion of the fabric mount. The perpendicular configuration was obtained by mounting the seam perpendicular to the motion of the fabric mount across the entire width of the fabric mount. The seam fabric samples were composed of a 420 denier, 6,6 nylon 49x49 construction with 35 stitches per 100 mm. The chain stitch was made using a 138 thread. The lock stitch used two thread types, 138 thread for the top and 92 for the bobbin. The woven was a 470 Decitex (420 Denier equivalent) fabric.

Table 1: Test matrix for the comparison of seam types.

Seam Type	Cushion	Set up Configuration	Number of tests
0	Control Sample	no fabric	3
1	Woven Unturned	Short Seams	3
2	Woven Turned	Short Seams	3
3	Sewn Turned	Short Seams	3
4	Sewn Chain Unturned	Short Seams	3
5	Sewn Lock Unturned	Short Seams	3
6	Woven Unturned	Tall Seams No Buckle Parallel	3
7	Woven Unturned	Tall Seams No Buckle Perpendicular	3
8	Sewn Unturned	Short Seams	3

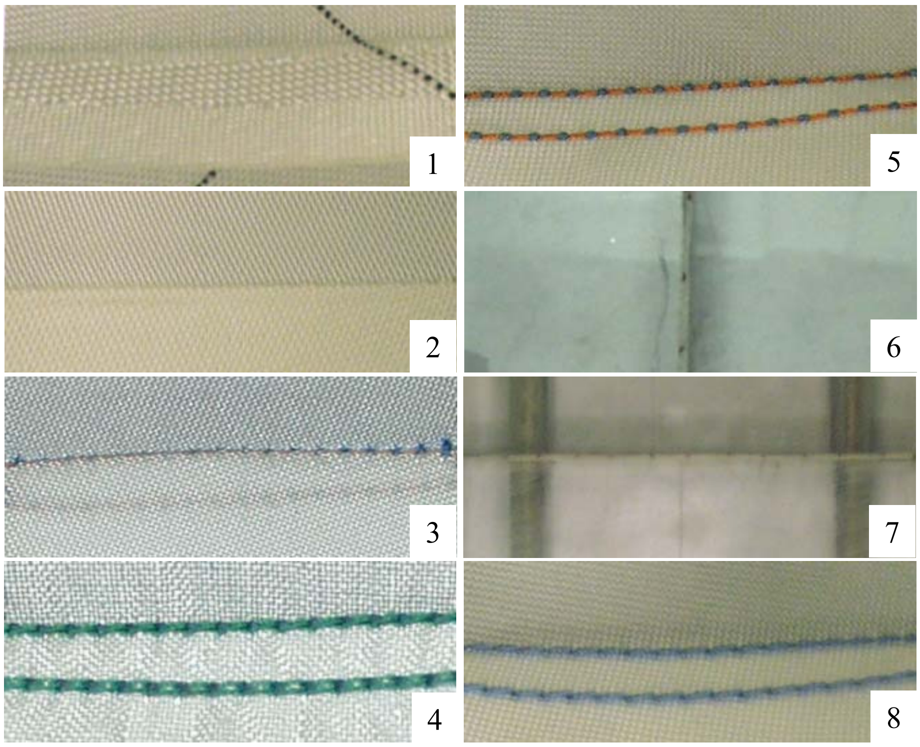
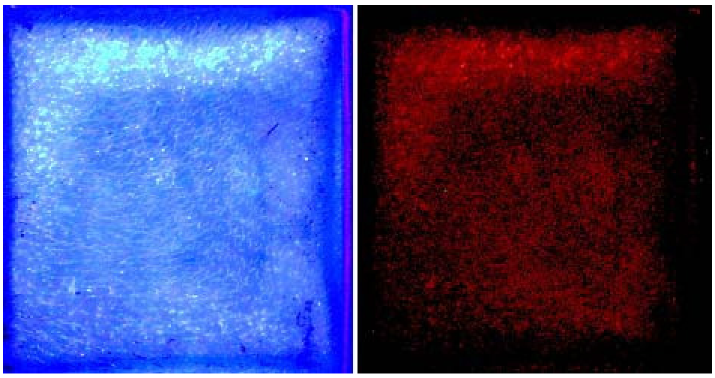


Figure 6: Images of the eight seam types used in the current study.

The eight different airbag seam types were prepared by cutting into a rectangular shape and mounting to a polycarbonate plate, or fabric mount (Figure 7). The mounting was such that the fabric was held in tension along all four directions. The airbag fabric was attached to the fabric mount and positioned for testing. The first three tests (Tests 1 – 3) were control tests that were performed using the fabric mount without fabric attached to it.

Figure 7: Polycarbonate fabric mount with fabric ready for testing.

After each test the tissue was removed and post-test photos were taken. Visual examination of the skin and fabric was facilitated using an ultraviolet light source and orange filters (Figure 8). The ultraviolet light caused the dermis to fluoresce. The appearance of this fluorescence was more apparent in the skin samples with a higher degree of abrasion. In cases where the abrasion was significant, the use of an orange filter increased the contrast between the exposed dermis and the remaining skin. The same image analysis was used to examine the fabric after each test to identify areas of the seam that had removed regions of the dermis from the skin sample.



a) b)

Figure 8: a) Ultraviolet light image of an abraded skin sample. b) Orange-filtered ultraviolet light image of the same sample.

Based on visually determining which section received the highest degree of abrasion from the photographic analysis, three sections (1.5 cm by 1.5 cm) of skin were removed for histology purposes. Two histological sections were collected from each of the three regions in an orientation perpendicular to the fabric path. In addition, two histological slides were developed from a control sample for each of the 27 tests. The control sample was taken from a region adjacent to the area to be tested. The histology slides from the control samples were analyzed to ensure that there was no pre-existing skin damage. So, for each test a total of eight slides were made, six from the abraded skin and two comparative controls.

ABRASION SCORING METHODOLOGY: To facilitate the analysis of the histology slides, an abrasion scoring method was developed. This scoring criterion incorporates both the depth of abrasion and the width of abrasion into a volumetric representation. Reed developed the Abrasion Rating System (ARS) that was used to indicate the severity of skin abrasion as a function of depth (Reed 1992). The system breaks the depth of injury into five categories ranging from partially through the epidermis (ARS = 1), to completely though the dermis (ARS = 5). These values were obtained by light microscopic analysis of the histological samples. The Width of Abrasion Rating System (WARS) was employed to relay the severity of the width of abrasion, as a percent of the total width of the histological skin sample. This system divides the width of the abrasion into three categories: WARS = 1 for less than 25%, WARS = 2 for 25% to 75%, and WARS = 3 for greater than 75% of the total width of the specimen. The Combined Abrasion Rating System (CARS) score combines both rating systems to give a score that is representative of the area of tissue removed (Figure 9).

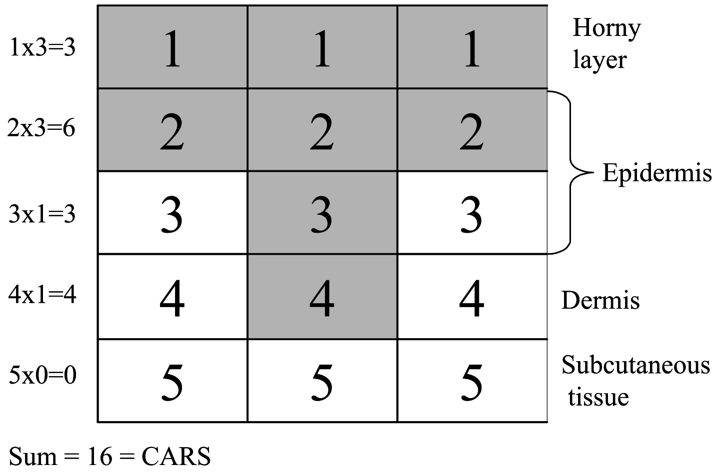


Figure 9: Example of a CARS score of 16 for a skin section with the abraded area shaded.

The two scores from the histology slides for each of the three sections were average, and the resulting three averages were then added to produce the Total Abrasion Score (TAS) for that test (Figure 10). The TAS score is effectively a weighted volumetric measure of skin that was removed for a particular test. This yielded a more precise indication of the severity of the abrasion caused during that test due to the effects of depth on pain and time required for the wound to heal.

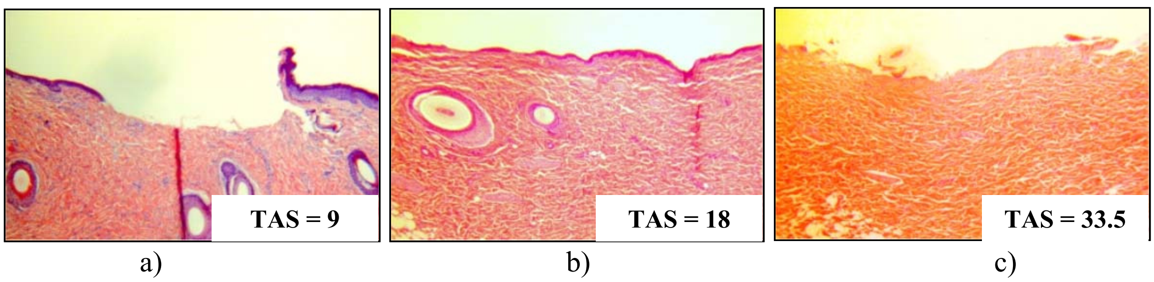


Figure 10: Histological comparison between three different tests using the Total Abrasion Score (TAS). a) TAS = 9.0, Average Maximum ARS = 1.83, Average Maximum WARS = 1. b) TAS = 18.0, Average Maximum ARS = 2, Average Maximum WARS = 3. c) TAS = 33.5, Average Maximum ARS = 3, Average Maximum WARS = 2.5.

Statistical analysis was performed to determine if the injury results were significantly different between seam configurations. Two tailed student t-tests were performed assuming unequal variances to compare the different configurations and the data gathered during each test. In addition, regression analysis was used to compare the peak and averaged velocities with the total scores, averaged maximum width and averaged maximum depth to determine their effects. Also, the peak and the averaged peak pressures were compared to the injury results to determine their effects.

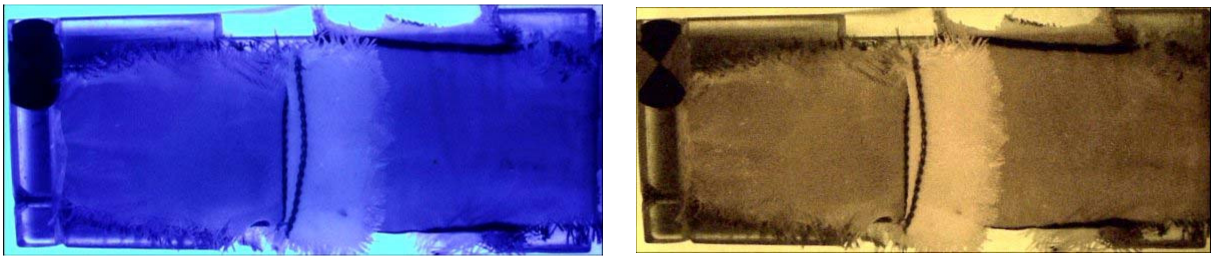
RESULTS

No abrasions were observed in the three control tests, but abrasions were observed in all 24 of the tests with airbag fabric (Table 2). In the control tests, Tests 1 through 3, the lack of skin injury indicates that the system and high-speed impact event by themselves do not cause injury. In contrast to the control tests, the 24 tests with fabric all resulted in skin abrasions that ranged from minor removal of epidermal tissue to more severe abrasions into the subcutaneous level. For all tests, The maximum average velocity observed during was 95 m/s (213 mph), with an overall average velocity of 84.8 m/s (190 mph). These velocities are consistent with the desired experimental goal and place the tests at the higher end of actual airbag fabric velocities.

Table 2: Test results from skin abrasion tests.

Test	Seam Type	Peak Velocity mph (m/s)	Average Velocity mph (m/s)	Peak Pressure psi (MPa)	Average Max Pressure psi (MPa)	Average Max Depth	Average Max Width	Total Abrasion Score
1	0	209 (93)	200 (89)	219.55 (1.51)	145.34 (1)	0	0	0
2	0	217 (97)	184 (82)	210.49 (1.45)	142.5 (0.983)	0	0	0
3	0	232 (104)	187 (84)	31.03 (0.21)	14.52 (0.1)	0	0	0
4	1	217 (97)	213 (95)	427.2 (2.95)	242.89 (1.68)	1.17	2.33	18
5	1	233 (104)	207 (92)	257.12 (1.77)	175.2 (1.21)	2.17	1.33	17
6	1	216 (97)	194 (87)	268.07 (1.85)	146.43 (1.01)	2.17	1.83	19
7	2	216 (97)	200 (89)	256.83 (1.77)	143.2 (0.988)	3.5	2.17	39
8	2	197 (88)	170 (76)	155.35 (0.8)	93.94 (0.648)	1.67	2	14.5
9	2	197 (88)	192 (86)	310.74 (2.14)	188.51 (1.3)	1.17	2	15
10	3	212 (95)	187 (84)	272.67 (1.88)	142.21 (0.981)	2.5	2	27
11	3	212 (95)	187 (83)	269.32 (1.86)	155.39 (1.07)	1.33	2.33	9
12	3	197 (88)	182 (81)	569.94 (3.93)	419.7 (2.89)	2.83	2.33	27.5
13	4	199 (89)	177 (79)	272.76 (1.88)	158.04 (1.09)	2.5	2.5	31.5
14	4	197 (88)	193 (86)	217.04 (1.5)	101.7 (0.701)	3	2.5	33.5
15	4	202 (90)	194 (87)	207.01 (1.43)	201.72 (1.39)	2.67	2.5	30.5
16	5	212 (95)	183 (82)	235.23 (1.62)	149.4 (1.03)	2	3	18
17	5	202 (90)	188 (84)	268.96 (1.85)	177.54 (1.22)	2.17	2.83	22
18	5	202 (90)	192 (86)	220.96 (1.52)	201.68 (1.39)	1.5	2.17	9.5
19	6	200 (89)	178 (79)	261.07 (1.8)	182.38 (1.26)	3.83	1.33	32.5
20	6	192 (86)	180 (81)	166.14 (1.15)	82.32 (0.568)	3	1	19
21	6	201 (90)	178 (80)	67.45 (0.47)	50.16 (0.346)	3.5	1	24
22	7	235 (105)	184 (82)	274.44 (1.89)	198.95 (1.37)	2.17	2.17	15.5
23	7	217 (97)	200 (89)	274.44 (1.89)	176.09 (1.21)	1.83	1	9
24	7	233 (104)	217 (97)	218.13 (1.5)	175.12 (1.21)	3.17	2.33	31.5
25	8	212 (95)	202 (90)	166 (1.14)	139.15 (0.96)	2	1.83	13.5
26	8	199 (89)	188 (84)	156.56 (1.07)	133.19 (0.919)	2.67	2	32
27	8	212 (95)	186 (83)	371.34 (2.56)	228.71 (1.58)	2	2	16

The photographic images indicated that the tissue transfer occurred primarily on the seam portion of the fabric samples (Figure11). This trend was not readily observed in normal lighting conditions, but clearly visible under ultraviolet light and when using ultraviolet light and an orange filter.



a) b)

Figure 11: Photographic post-test images of Test 14 a) Ultraviolet light image of a mounted fabric sample. b) Orange-filtered ultraviolet light image of the same sample.

In order to ensure that the airbag seam sample was the only experimental parameter that contributed to the level of skin injury, an analysis was performed to compare the experimental parameters with the observed skin injury outcomes. The very low linear regression correlation coefficients for the different test parameters illustrate that there was no relationship between the test parameters, other than seam type, and the resulting abrasion (Table 3). This is shown to be true for the velocity and pressure measures in relation to the three primary injury measures: average maximum depth, average maximum width, and total abrasion score. These results prove that the airbag seam configuration was the only contributor to the level of skin injury, and that the other experimental parameters were held sufficiently constant throughout the 27 tests.

Table 3: Linear regression correlation coefficients with respect to test parameters.

	Peak Velocity	Average Velocity	Peak Pressure	Average Peak Pressure
Average Max Depth	0.0100	0.0172	0.0456	0.0321
Average Max Width	0.0002	0.0026	0.0866	0.0944
Total Abrasion Score	0.0212	0.0003	0.0002	0.0010

Seam type 6 resulted in the average deepest abrasions with ARS scores ranging from 3 to 3.85; however, this type also resulted in some of the most narrow abrasions with WAR scores ranging from 1 to 1.33. This trend is expected given the narrow configuration of the woven unturned seam in the parallel loading direction of Tests 19 through 21. In contrast, seam type 5 resulted in the greatest width scores ranging from 2.17 to 3, but lesser depth scores ranging from 1.5 to 2.17. Overall, seam type 4 resulted in the greatest average TAS score with all three tests above 30.5.

Two-tailed t-tests assuming unequal variance were performed to determine significant differences between the different seam designs and configurations (Appendix Tables 4-6). While there are countless comparisons, several are of particular interest. First, the effect of turning the airbag inside or out can be examined by direct comparison. For example, in the seam designs with sewn seams, the type 4 was unturned compared to the similar turned style 3. The TAS scores were higher for type 4, but not significantly ($p = 0.22$). Similarly, the woven airbag seam style can be compared for the effect of turning the airbag inside out or not by comparing the turned type 1 with the unturned type 2. In contrast to the sewn styles, there was much less difference in turning the airbag inside out or not with the woven seam types as seen with a much higher p-value ($p = 0.61$).

An additional comparison can be made directly between the woven styles and the sewn styles. In particular, the TAS score for the sewn chain unturned seam was significantly ($P=0.01$) higher than that of the woven unturned seam. Also, the sewn chain unturned seam produced significantly ($P=0.015$) wider abrasions than the woven turned seam. Within the woven seam types, the effect of loading direction can be examined. The average TAS scores were not significantly different for the two loading directions between seam type 6 and 7 ($p = 0.22$) (Figure 12). However, the composition of the width and depth scores were different as the parallel loading resulted in deeper but less wide abrasion.

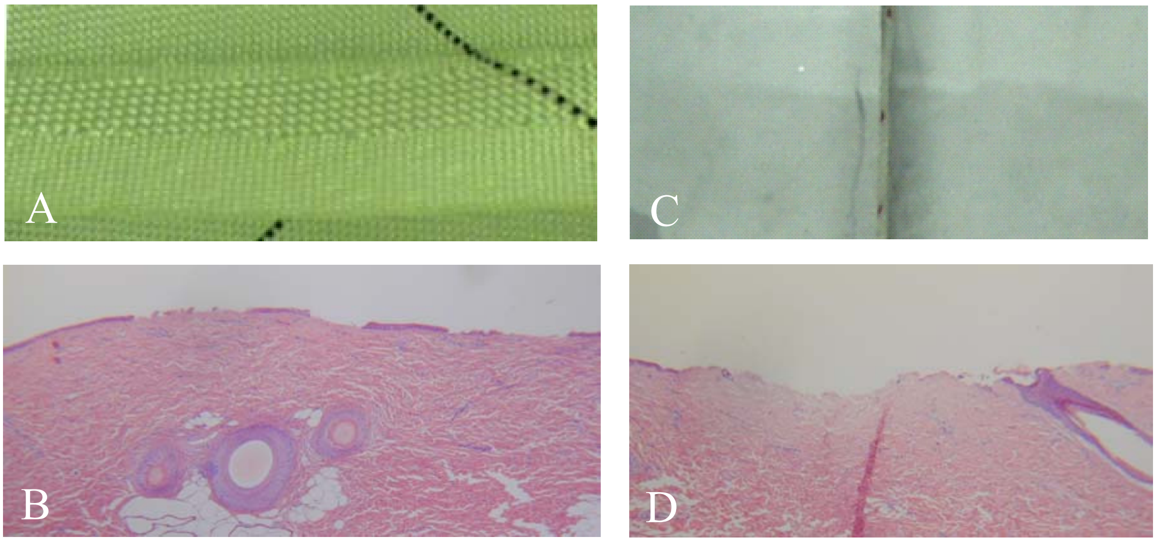


Figure 12: Seam and histology results for woven unturned seam (a) and histology result from Test 4 (b) with TAS of 18, in comparison to woven unturned parallel seam (c) and histology result from Test 20 (d) with TAS of 19.

DISCUSSION

The analysis of the results obtained from these tests show that it is possible to measure the effects of different airbag fabric and seam designs on the level of skin abrasion with respect to shear loading. The variety of airbag fabric designs used during these tests indicate that any type of airbag fabric is capable of producing some type of abrasion, although in some cases this is limited to a partial removal of the epidermis. The most severe abrasions induced during these test were limited to the dermal layer, while no abrasion removed the full thickness of the dermis. The use of the Abrasion Rating System (ARS), and the development of the Width Abrasion Rating System (WARS), and Total Abrasion Score (TAS) scores proved beneficial in the quantification of the overall severity of skin abrasions caused by different airbag fabric and seam types. The TAS score yields a volume relation to the abraded region that is weighted on depth of the abrasion. Weighing the TAS score more heavily on depth provides a better description of abrasion severity on a human subject. One limitation of this system is that there are a limited number of permutations for each abrasion. This is limited by the ability to discern abrasions into different groups. For example, the WARS is limited to three groups due to the inability to refine this score further without losing repeatability or accuracy.

Previous research on skin abrasions has focused on normal loading only. The methods and results presented in the current study illustrate that shear loading should be considered in addition to normal loading, and that severe abrasions can be caused by normal pressures well below the 1.75 MPa injury threshold previously published. The statistical analysis showed no correlation between the depth or width of the resulting abrasions and the peak pressures exerted onto the skin during the test. The TAS score also showed no correlation with the peak average peak pressure exerted onto the skin. These particular results indicate that the resulting abrasions are purely a function of the seam and fabric design and not the test apparatus.

Although the majority of the statistical comparisons between seam designs were not found to be significantly different, several important differences were shown to be significant. Given that only three tests were performed with each design, any significant difference represents substantial difference. Moreover, it is expected that many more significant differences could be elucidated by increasing the test sample size for each seam configuration.

CONCLUSIONS

The new shear loading configuration proved effective at simulating a deploying airbag in a manner that allowed for the accurate comparison of seam construction types. By using histology sections to investigate the severity of the abrasions, the newly created total abrasion score was able to characterize deeper and more severe abrasions relative to wider and less severe abrasions. This new methodology utilizes active pressure sensors for monitoring normal contact pressure in real time. By using ultraviolet light photographic techniques, abrasions, which expose the dermis, may be located on the skin sample as well as the airbag fabric. The combination of these techniques allows for the direct comparison of airbag construction types on the risk of skin abrasion. The results indicate a significant increase in the severity of skin abrasion from a sewn unturned airbag seam in comparison to woven seam unturned seam. Moreover, while turning was not shown to be a significant factor, there was a larger effect on the results for turning sewn airbags than the woven seams. While the shear methodology presented here allows for a direct comparison of seam design, it should be utilized in conjunction with normal loading evaluation procedures. It is hoped that the combination of shear and normal loading tests will prove beneficial for the design and implementation of future airbag seams to reduce the risk of skin abrasions.

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APPENDIX

Table 4: P-values for average maximum depth of abrasion.

Seam Configuration	1	2	3	4	5	6	7	8
1								
2	0.746							
3	0.528	0.903						
4	0.093	0.488	0.405					
5	0.895	0.791	0.550	0.028*				
6	0.017*	0.217	0.098	0.084	0.008*			
7	0.346	0.756	0.797	0.492	0.346	0.109		
8	0.403	0.895	1.000	0.157	0.328	0.020*	0.740	

*Statistically Significant

Table 5: P-values for average maximum width of abrasion.

Seam Configuration	1	2	3	4	5	6	7	8
1								
2	0.529							
3	0.298	0.272						
4	0.147	0.015*	0.130					
5	0.096	0.144	0.208	0.580				
6	0.102	0.005*	0.002*	0.006*	0.011*			
7	1.000	0.652	0.465	0.253	0.188	0.238		
8	0.742	0.230	0.111	0.010*	0.109	0.007*	0.817	

*Statistically Significant

Table 6: P-values for average total abrasion score.

Seam Configuration	1	2	3	4	5	6	7	8
1								
2	0.611							
3	0.656	0.877						
4	0.001*	0.384	0.225					
5	0.727	0.527	0.559	0.056				
6	0.214	0.812	0.620	0.241	0.183			
7	0.930	0.712	0.796	0.190	0.795	0.464		
8	0.710	0.826	0.941	0.193	0.601	0.542	0.846	

*Statistically Significant