

The Influence of Animal Glue on Mechanical Properties of Painting Canvases

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Abstract

Glues derived from animal products have been used in the preparation and conservation of painting canvas for hundreds of years. However, it is not clear how exactly these adhesives contribute to the mechanical strength of a canvas and how this contribution changes with time. This comparative study looks at the effect of age, thickness, and type of animal glue on the mechanical reinforcement the glues provide to canvas. Isinglass, rabbit skin, bovine hide and bone glue are compared. The mechanical strength of the canvas and glue system have been measured with a tensile test. The influence of glue on the tensile response of canvas has been observed in the slope of the initial region of the stress-strain curve for these samples. This region has been identified as the initial load-bearing region which corresponds to the glue coating. The major contributing factor to change mechanical reinforcement of canvas is found to be the degradation of the glue, however the type of glue used plays a small role as does the thickness of the glue applied.

1. Introduction

Painting conservators are constantly looking for ways to increase the strength of painting canvases. One of these methods is canvas lining, where an additional canvas is adhered to the painting canvas as a support to provide additional mechanical strength. This practice has taken many forms over its history of use. A variety of application techniques, tools, and materials have been used. Some lining treatments are done with a full lining canvas covering, other have just a strip treatment to the region of high stress near the stretcher bars, and others are just covering tears in the painting canvas (1). The tools and materials used in lining have changed drastically with time. Early lining treatment in the late 19th and early 20th centuries mostly involved applying an adhesive made of animal glue and paste to an un-stretched painting canvas and then hand ironing on an additional lining canvas (2). Concerns about the longevity of the paintings caused this treatment to become a standard preventative measure of conservation. The treatment was undertaken almost as insurance against the future damage to paintings (3). However, this technique relied heavily on the steadiness of the conservator's hand to avoid the risk of damage to the painting by means of flattening. The paste-glue mixture was quite susceptible to hygroscopic and thermal fluctuations. A wax-resin adhesive rose to prominence due to its atmospheric inertness in the early 20th century, but this adhesive led to the impregnation of the painting's pigments with a darker hue (4–6). New technological developments led to the improvement of the application tools; this brought the invention of the vacuum hot table that would replace hand ironing (6, 7). While this tool was invented to reduce the forces on the painting canvas, the flattening effect was still occurring due to the high heat.

Growing concerns with the immediate and long-term effects of lining on canvas reached its pinnacle with the Greenwich Conference in 1974. One of the main concerns was the so-called 'lining cycle' outlined in Westby Percival-Prescott's research, who pointed out that a lined canvas would eventually need to be relined due to the degradation of the lining and adhesive, placing the painting in a cycle of invasive treatments that without initial lining would have been avoidable (8).

After the Greenwich Conference, the tools and materials developed for lining changed drastically. This included the development of a cold table with air flow that reduced the amount of heat being applied directly on the canvas (9). New adhesives were developed during this time such as Gustav Berger's BEVA copolymer (10, 11). This synthetic glue was developed with conservation specific properties in mind. Other lining canvas materials were also considered during this period, such as sailcloth (12).

Towards the end of the 20th century, the use of lining as a treatment has decreased as shown in surveys conducted in 1975, 1984, and 2001 (13). This left the problem of treating canvases that had already been lined and were now engaged in the "lining cycle" (8).

Cotton canvas is the material for lining for paintings that this study focuses on. Canvases traditionally have been made from cotton, linen, or jute. The major component of cotton canvas is cellulose, a polymer that is able to form both crystalline and amorphous regions. The polymer chain backbone forms hydrogen bonds with the other parts of the polymer backbone giving the cellulose its strength. The degradation of cellulose is through hydrolysis where the chain is broken (14). This leads to a reduction of the tensile strength and other mechanical properties of the cellulose. This degradation is acid-catalysed and can be assessed by measuring the degree of polymerisation of the cellulose in canvas through viscometry. The weakening of canvas through chemical degradation prompts the re-treatment, often with a relining of the canvas.

The term glue in this study is used to refer to an adhesive as used in conservation practice. The glues used in this study are rabbit skin glue (RSG), isinglass (a glue made from a sturgeon bladder originating from Russia) and bovine hide and bone glue. These glues have been historically used for conservation treatments, including lining and consolidation treatments. The purpose of consolidation treatments is to reattach flakes of paint, historically achieved through lining (1). These glues are all collagen based and therefore exhibit similar degradation mechanisms. Collagen is made up of a long protein chain that has been denatured in order to become soluble in water and form gelatine. The formation of gelatine is essential for collagen to become a successful glue. Once denatured, the now free functional groups are able to form hydrogen bonds leading to the glues gel and adhesive properties. Research in the past has focused on the response of glue to environmental fluctuations but there is significantly less information about the degradation behaviour of collagen based glues (15, 16). Earlier research has shown that with thermal and ultraviolet ageing, mammalian animal glues (RSG, bovine hide and bone) will increase tensile strength and become stiffer and more brittle whereas isinglass will remain more elastic (14).

The research on canvas lining has historically focused on the immediate effects of lining. Studies are now focusing on the longevity of the treatment and how to manage collections with lined paintings. There still are many gaps in the understanding of the degradation of canvas and glue and how this contributes to the overall mechanical strength of the painting. This study aims to understand what mechanical reinforcement traditional animal glue itself provides to canvas and how this reinforcement changes during degradation. The variables in the experiment are the type of glue, degradation of canvas,

degradation of glue, and thickness of glue. Tensile testing is used to determine the mechanical strength of the samples.

2. Materials And Methods

This study is divided into 5 different experiments, each comparing the effect of a different variable on the mechanical response of the canvas. The 5 experiments are listed in Fig. 1. The first experiment focuses on the difference between new and degraded canvas without glue. The second focuses on RSG that has been degraded for up to 4 weeks and applied to new and degraded canvas. The third experiment focuses on the glue type used; RSG, isinglass, bovine bone and hide glues have all been applied to new and degraded canvas. The fourth compares the effect of multiple layers of RSG applied to new and degraded canvas. Finally, an experiment is done using a sacrificial historic canvas with no glue, 1 layer, and 2 layers of RSG. The acronyms that will be used to describe variables in this study have been defined in Table 1.

Table 1
Summary of the experiments, samples, and sample codes used in the text.

| Experiment | Samples |
|--------------------|-------------------|
| Canvas Degradation | New |
| | Degraded |
| Glue Degradation | 0 weeks (0wG) |
| | 1 week (1wG) |
| | 2 weeks (2wG) |
| | 3 weeks (3wG) |
| | 4 weeks (4wG) |
| Glue Type | Rabbit Skin (RSG) |
| | Isinglass |
| | Bone |
| | Hide |
| Number of Layers | 1 layer |
| | 2 layers |
| Historic Canvas | 0 layers |
| | 1 layer |
| | 2 layers |

2.1 Canvas Preparation

The study used un-primed cotton duck 12 oz canvas from L. Cornelissen & Son (London, UK) with an average weight of 480 g/m² and an average thickness of 0.77 mm. The canvas was washed eight times in a washing machine, twice at 95 °C and 6 times in water without soap at 60 °C to remove any chemical residues left from processing. The canvas was then laid out to dry and cut into smaller pieces, of 300 mm by 110 mm. It was then rinsed in a cold-water bath by hand and pressed between pieces of filter paper (Whatman) to flatten the canvas before drying in an oven at 60 °C for 5 h. The pH (7.2 ± 0.1) and degree of polymerisation (6200 ± 250) were measured to establish the initial material properties of the canvas. This was done with a pH meter (Mettler Toledo) using the cold extraction method and a capillary tube viscometer according to ISO standard 5353:2004. The canvas was thermally degraded for 9 days at 120 °C, at 130 °C for 6 days, and at 150 °C for 12 h. This staggered ageing was done due to time constraints and the need to achieve a set level of degradation, which was < 1000 , as is usual for a degraded canvas (17). Achieving this level of degradation is more important than the method of degradation as the effect on DP is the same regardless of the method of degradation. The DP was measured again after degradation and was 960 ± 20 , signifying the canvas was sufficiently degraded. The initial DP of canvas is ~ 14000 , reduced to ~ 2500 during processing (14).

A sacrificial historic canvas from the reference collection of UCL Institute for Sustainable Heritage was used as well for this study. This canvas came from an oil painting on cotton canvas from the 1950s. The DP was 1850 and pH 6.4. The paint layers were left intact during testing in order to minimise damage to the canvas. The region used was cut from the bottom right corner of the painting due to the relative consistency of the thickness of the paint layer determined by the pattern of the painting. This area of the painting image had limited details that suggested a more consistent application of paint.

2.2 Glue Preparation

Cow bone and hide (A.P. Fitzpatrick, London, UK) and rabbit skin glue (L. Cornelissen & Son, London, UK) were purchased in flake form and isinglass (L. Cornelissen & Son, London, UK) was purchased in powder form. In order to reproduce the methods most commonly used by conservators, the glues were purchased in the forms most frequently sold at the store. Animal glues would generally be prepared as a mixture with flour in a lining treatment but in order to test the glue itself, the glues were prepared without flour (2). The glue was soaked in water in a 2:1 water to glue mass ratio overnight and then heated in a hot water bath at 65 °C until the hydrated flakes liquefied. Traditionally, different types of glue would be prepared in different ratios but for the sake of consistency in glue concentration, the samples were all prepared with the same water to glue mass ratio (2). This allows the comparison of the same quantity of glues effects on the canvas for each glue type.

To obtain degraded glue samples, it was spread on a polyester sheet as thinly as possible and dried at $25\text{ °C} \pm 1\text{ °C}$ and $49\% \text{ RH} \pm 5\% \text{ RH}$. The sheets of glue were then broken apart into flakes measuring roughly 25 cm² in area and heated at 80 °C and 65% RH for 1 week, 2 weeks, 3 weeks, and 4 weeks in a Binder KBF 115 climate chamber (Tuttlingen, Germany). Once degraded, the glue flakes were soaked in

water until rehydrated over night with a 1:2 glue to water ratio and then heated until liquid. For the samples of non-degraded glue, the solution was prepared in the same method and applied directly to the canvas rather than to the polyester sheets.

2.3 Sample Preparation

The canvas was stretched on a wooden board on top of polyester sheets to prepare for glue application. Whilst warm, glue was applied to 300 mm x 110 mm sheets of canvas using a brush coating the entire surface of the canvas with an even layer. The canvas piece was weighed with a lab balance, glue was applied, the canvas dried overnight, and was then weighed again. For samples with two layers, another layer was added after the first layer had dried for 24 h. The thickness of the glue layer was determined by mass percent increase after the addition of glue. The samples were then cut using a scalpel to 25 mm x 100 mm specimens for testing. The thickness of each specimen was measured with a calliper prior to testing to determine the cross-sectional area. Thickness measurements were taken and averaged but there was the possibility for error due to inconsistency in thickness. The same volume of glue mixture containing the same mass of glue was applied to each sample of the same area but it was difficult to ensure the distribution within the canvas. Differences in glue thickness within a sample could create different strain responses. The careful application of minimised this source of error.

2.4 Testing

Tensile testing of the material was conducted using an Instron 5565A (Norwood, MA, USA). The machine is capable of conducting tensile and compression tests at a range of loads and speeds. To ensure all samples had the same drying of glue and moisture content, preconditioning was conducted prior to all mechanical testing. The samples were placed in an oven for 4 h to 5 h at 40 °C and then placed in the room with the Instron for 24 h to acclimatise to the conditions, 23 °C ± 2 °C and 50% RH ± 5% RH. The samples were tested in the warp direction with an extension rate of 50 mm/min and a gage length of 20 mm to failure (11).

There are many potential sources of error in the testing of these samples. As the samples are manually loaded, inconsistencies in loading angle, area of sample within the grips, amount of load at beginning of run, and tightness of the grips can all be sources of human error. This error is controlled by having one operator of the equipment and conducting all runs of the same trial at the same time to ensure consistent sample loading.

2.5 Analysis

The results from the tensile test are outputted as displacement in inches and strain in lbs, which will then be converted into a stress measurement in MPa and a normalized strain measurement. This is done by converting the displacement into mm and dividing by the length of the sample. The stress is calculated by converting to N and then normalising the measurement with the cross-sectional area of the sample. These two values can then be plotted on a stress-strain curve and the results analysed.

Several regions of the stress-strain curve are of interest to this research. In most samples, the initial stress-strain relationship is linear and represents the elastic region, where the material can deform elastically and return to its original condition. The slope of this line (the Young Modulus) correlates to the stiffness of the material. The next region of interest is the plastic region where deformation is permanent. These analyses were done in accordance to the ASTM International tensile testing standard (19).

3. Results And Discussion

The results of this study are divided into experiments in order to compare the effect of each variable on the mechanical response of the canvas. Table 2 shows each experiment and the ultimate load and displacement for each of the samples in that study. This allows comparison to be made between the studies.

The application of glue on the model canvases consistently lead to the saturation of the canvas where the glue fully soaked into the canvas and no more could be applied. This saturation lead to the question of whether the glue's contribution to the strain response was due to its impregnation of the canvas or as a coating layer (20). Visual observation of the tensile tests noted that initially during a tensile test, a cracking noise occurred that seems to correlate with the breaking of the coating layer. This noise would end before the ultimate canvas failure. In the future, the extent of impregnation versus coating effect could be measured by conducting parallel testing on individual yarns.

Table 12: Table showing the maximum load and displacement experienced by the various samples from experiments

| Experiment | Type of Canvas | Sample | Ultimate load (MPa) | Ultimate displacement |
|---------------------|----------------|-----------|---------------------|-----------------------|
| Degradation of Glue | New | 0wG | 24.3 ± 1.0 | 0.75 ± 0.10 |
| | | 1wG | 25.0 ± 0.8 | 0.68 ± 0.16 |
| | | 2wG | 24.2 ± 0.9 | 0.69 ± 0.11 |
| | | 3wG | 24.6 ± 1.1 | 0.69 ± 0.04 |
| | | 4wG | 23.2 ± 1.6 | 0.59 ± 0.12 |
| | Degraded | 0wG | 10.1 ± 1.0 | 0.53 ± 0.13 |
| | | 1wG | 11.0 ± 0.9 | 0.48 ± 0.08 |
| | | 2wG | 13.2 ± 2.0 | 0.43 ± 0.04 |
| | | 3wG | 12.0 ± 1.0 | 0.52 ± 0.13 |
| | | 4wG | 10.9 ± 0.9 | 0.48 ± 0.13 |
| Glue Type | New | RSG | 24.3 ± 1.0 | 0.75 ± 0.10 |
| | | Isinglass | 21.3 ± 1.5 | 0.57 ± 0.13 |
| | | Hide | 25.2 ± 1.7 | 0.60 ± 0.09 |
| | | Bone | 21.9 ± 1.56 | 0.67 ± 0.20 |
| | Degraded | RSG | 10.1 ± 1.0 | 0.53 ± 0.13 |
| | | Isinglass | 11.3 ± 0.5 | 0.59 ± 0.14 |
| | | Hide | 10.9 ± 0.4 | 0.51 ± 0.15 |
| | | Bone | 11.2 ± 1.1 | 0.55 ± 0.07 |
| Thickness | New | 1L | 23.2 ± 1.6 | 0.59 ± 0.12 |
| | | 2L | 21.9 ± 3.2 | 0.66 ± 0.11 |
| | Degraded | 1L | 10.9 ± 0.9 | 0.48 ± 0.13 |
| | | 2L | 10.9 ± 1.4 | 0.51 ± 0.09 |

Further visual assessment revealed that the glue layer significantly increased the stiffness of the canvas. Generally, there exists an inverse relationship between the flexibility of the adhesive and its film strength, i.e. as the strength of the adhesive increases, its flexibility will decrease. It has been seen as beneficial to have more flexible adhesives with a lower overall strength as it is unlikely that the strain experienced by canvas or textiles will reach the ultimate tensile strength (21). This is an important factor to keep in mind as the various glues in this study are analysed. Another interesting visual observation was in the brittleness of the glue upon drying. To condition the samples for testing, all samples were fully dried at 40 °C. After this drying, the samples all seem to exhibit similar brittleness as it was difficult to straighten

curls that appears at the edges of the canvas. This effect was widespread but most apparent in the historic canvas samples. This could be related to an increase in the coating effect for historic canvas as the paint layer on the canvas made saturation and impregnation more difficult.

On the stress-strain curve for some trials, an initial region of delay was observed. This was a region where no stress change or increase was recorded a period of strain increase. This appears as a flat line at the beginning of the stress-strain curve. This delay could be due to a variety of factors. One is that the sample started out in slack when testing began and strain was only recorded once the sample was in tension. Another explanation involves the crimp of the canvas yarn. Crimp is the bend in yarn from weaving. Upon application of pressure, the first reaction of the canvas is straightening the crimp from the yarn and then the matrix of the canvas begins to bear the load (22). As the appearance of this delay is not consistent through all trials, it is more likely the inconsistency in initial slack that causes the appearance of delay in some samples and not others and not due to the crimp.

3.1 Effect of canvas degradation

Figure 1 compares the stress-strain curve of the 3 types of canvas used in this study: new, degraded, and historic. The degraded and new canvas both display two regions in their curves while the historic canvas only has one region. The second region of the degraded and new canvas and the only region of the historic canvas all have a similar slope of 190 ± 10 MPa. This region seems to correspond to the plastic region of the curve, suggesting that the historic canvas cannot deform elastically and that any deformation will lead to permanent change in the canvas. This is an interesting observation as the DP of the historic canvas is higher than that of the artificially degraded canvas, which implies that it is less degraded and therefore should exhibit higher strength. This result can be explained by the paint layer that was retained on the historic canvas during tensile testing; this additional layer may alter the way the canvas responds to stress as part of the stress is initially distributed by the paint layer. Similarities between the model canvases also makes sense as the canvases are from the same cut while the historic canvas has obviously been manufactured elsewhere. The breaking point for the historic canvas occurs first at the lowest strain value, followed by the degraded canvas and then the new canvas. This, again, supports the fact that although the DP for the historic canvas is higher than that of the degraded canvas, it will deform less than the degraded canvas and break more easily. Another observation of interest is that the maximum stress value for the historic and degraded canvas is the same, meaning that although the two canvases will have different displacement values, the ultimate load for both is equivalent. The maximum load and displacement for the new canvas is higher than both other canvases.

In the following analyses, the effect of different glues will be compared on each of the different types of canvases. This allows the results to be associated to the variables in the glue rather than differences in the canvas.

3.2 Effect of glue

The application of glue to any of the canvases tested leads to the addition of a region to the stress-strain curve. This region appears to correspond to the effect of glue on the canvas which is apparent in Fig. 4. The glue delays the response of the canvas, which is not measurable until a higher stress is applied. This effect has been observed in other studies; the glue acts as the major load-bearing component until its failure and then the canvas will start bearing the load (14).

Table 2
Comparison of the slopes of the various regions for a new canvas with and without RSG

| Sample | Slope 1st Region (MPa) | Slope 2nd Region (MPa) | Slope 3rd Region (MPa) |
|---------------------|------------------------|------------------------|------------------------|
| New Canvas, No glue | 29.4 ± 7.3 | 198 ± 52 | – |
| New Canvas, RSG | 86 ± 16 | 23.9 ± 5.2 | 185 ± 14 |

This result is supported by the fact that the slope of the first region is consistent between glue types applied to different canvas types. When the same glue is applied to different types of canvas, the slope of the first region is constant. The slopes of the second and third regions match the canvas type regardless of glue applied, as shown in Table 2. This shows that the first region is the glue layer component of the stress-strain curve.

The normal maximum stress that a canvas experiences whilst on the stretcher is 20 N (14). This value consistently falls in the first region of the stress-strain curve. This indicates that when glue is applied to the canvas, the maximum load the canvas experiences will generally not exceed the glue strength; the glue remains the major load-bearing component in the average lifetime of a canvas. This is important as it means that the glue strength could determine whether the canvas is affected by stress or not. Thus, it is important to determine what variables define the tensile properties of the glue.

3.2.1 Effect of glue degradation

Figure 5 represents the slope of the first region of the stress-strain curve for RSG aged to varying extents. The top region shows the results for glue applied to the new canvas and the bottom region shows the results for glue applied to the degraded canvas. The glues are ordered from most degraded (4 weeks in an oven) to least degraded (fresh glue). Based on these results, regardless of the type of the canvas that the glue was applied to, less degraded glue yielded stiffer canvas response. This response makes sense as the degradation mechanism for RSG involves the breaking down of collagen and the shorter the chains, the more brittle and less effective the glue. This result suggests that degradation of glue is a concern for effective relining, as it can measurably reduce its protective capacity. The degradation of glue leads to a general decrease in the ultimate displacement of the sample as seen in Table 1, meaning a decrease in the elasticity of the canvas. These results are contrary to what was discussed in the study by Carr et al. (9). This could be due to the different method of accelerated degradation used (UV photo-degradation was used in their research) or due to a different method of analysis. The derivation of their

thickness measurement is not fully explained, which could suggest a different approach to analysis that perhaps did not take into account the glue region of the stress-strain curve.

3.2.2 Effect of the type of glue

As various types of glues are used in practice, it is important to compare these glues and see how they respond in the same circumstances. Figure 6 shows the range in which the glue effect is noticeable; this refers to the region of the plot where slope increases for the first time. The values of the stress that correspond to this region have been plotted for the different types of glue applied to both new and degraded canvas. The regions themselves do not vary too greatly by general stress value or by size of range in which glue effect is noticeable. Hide seems to have the longest of the ranges which is a desirable trait. Isinglass has the shortest range. However, due to the statistical significance of these results, the change in range length does not seem to be a significant difference between the different types of glue.

Figure 7 shows a comparison of the stiffness of different glue types. Hide seems to provide the stiffest support, although the results for the new canvas have quite a large standard deviation. The RSG had the lowest stiffness. Low stiffness quality could be considered desirable in this context as a high stiffness can hinder natural movement in the canvas and in turn create additional stresses.

Based on the collected results, RSG seems to have an adequately large region where the glue acts as the major load-bearing component and provides a lower stiffness. The lower stiffness value is desirable in this context in comparison to the results for canvas degradation. A decrease in stiffness means a weakening of the glue and thus the glue-canvas system where as a low initial stiffness means flexibility in the canvas.

3.2.3 Effect of thickness of glue

When a second layer of glue is applied, the assumption would be that an increase in thickness of glue would lengthen the glue region of the curve and increase the stiffness.

The results shown here show a varying effect based on the canvas degradation. For the new canvas, an increase in thickness leads to an increase in stiffness whereas for the degraded canvas this difference is not statistically significant. The change in stiffness would make sense if it were different on different canvases to a different scale, but this difference is not logical as the change is now happening in the opposite direction. The same is true when considering the range of the glue effect on canvas. With an increase in glue, one would assume there would be an increase in the region of the glue effect. For the new canvas, this is true, yet, for the degraded canvas the opposite is true. The ultimate displacement values show an increase with an additional layer for both types of canvas as shown in Table 1. While the margin is small, this result does show a significant difference with the addition of a layer.

3.3 Historic Canvas

The testing of the historic canvas was conducted with no glue, with 1 layer of RSG and with 2 layers of RSG. The additional layer was observed to make a significant difference in the range of the load the glue bears. With one layer, the glue could bear stresses up to 0.03 MPa, while two layers could bear stresses up to 0.8 MPa. This result is markedly different than the trend observed in the model canvases. This could be due to the interactions with the paint layer. The application of the glue while there is a paint layer is quite different than when applied with no other changes to the canvas. With a clean canvas, the glue saturates the canvas while a canvas that already has sizing or paint layers will have the glue sit atop the canvas more and not allow it to penetrate as thoroughly. This would lead to the second layer acting as a second coating rather than impregnating the canvas again.

It would be of interest to test the historic canvas with and without the paint layer removed and compare how glue is absorbed by the canvas. This is an important phenomenon as the canvases that will be receiving treatment will generally have a paint layer or ground layer already. If the existence of a paint layer hinders the impregnation of glue in canvas, then future studies should focus on canvas that has been coated not saturated with glue as this will more adequately mimic conditions in practice.

4. Conclusions

The study explored the variables that affect glue performance as an adhesive for conservation treatment and analysed which variable played the largest role in changing the mechanical strength of the sample. The results have shown that the application of glue to a canvas results in the glue layer acting as a load-bearing layer. This layer creates another region in the stress-strain curve of the material that corresponds to the properties of the glue applied. Analysis and comparison of this region allowed the different types of glue applied to be easily compared.

Upon comparison, it appears that the degradation of glue leads to a decrease in its stiffness. This trend was observed in both new and degraded canvases. The properties of glue have been shown to change with time and this change could alter the way that the canvas reacts to stresses. The effect of the type of glue was less significant. The measurements of the Young Modulus were all quite similar, however RSG, which is the glue of choice for conservators, did appear to have the most desirable tensile properties, an adequately large region where the glue acts as the major load-bearing component and provides a lower stiffness, which corresponds with it being the choice glue for conservation treatments although the differences between glues was minimal. The results for variation in the thickness of the glue by applying 1 and 2 layers of glue were inconclusive. Future studies will have to evaluate this phenomenon further. This is due to the inconsistency in results when applied to new and degraded model canvases. Upon application to the historic canvas sample, an increase in glue thickness lead to the expected results: an increase in the range of stress that the glue coating bears. Since the results from the thickness trials for the model canvases were inconclusive it is difficult to tell if this is a general effect of an increase in thickness or if this is directly related to the historic canvas and perhaps a product of having the paint layer intact preventing full saturation of the canvas.

Overall, it appears that of the studied variables, glue degradation is the one with most impact on the way a glue-coated canvas responds to mechanical stress. This could be of concern as this variable is often difficult to measure in practical conservation situations. This research prompts the question of the limits of this effect and solutions for treatment. Future research should explore the extent of degradation at which glue no longer provides additional support to the canvas. Once this value has been ascertained, techniques could be explored to minimise the impacts of ageing glue. As it is not known how the application of fresh glue on top of degraded glue could enhance its mechanical properties, all reinforcement methods using a surface application of a consolidant would benefit from glue degradation research as proposed here.

Declarations

Availability of data and materials

All data generated or analysed during this study are included in this published article

Competing interests

The authors declare that they have no competing interests.

Author's Contributions

JG, MS and AD designed the experimental protocol. JG and AD produced the figures. AD conducted the statistical analysis. All authors contributed equally to the manuscript.

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Figures

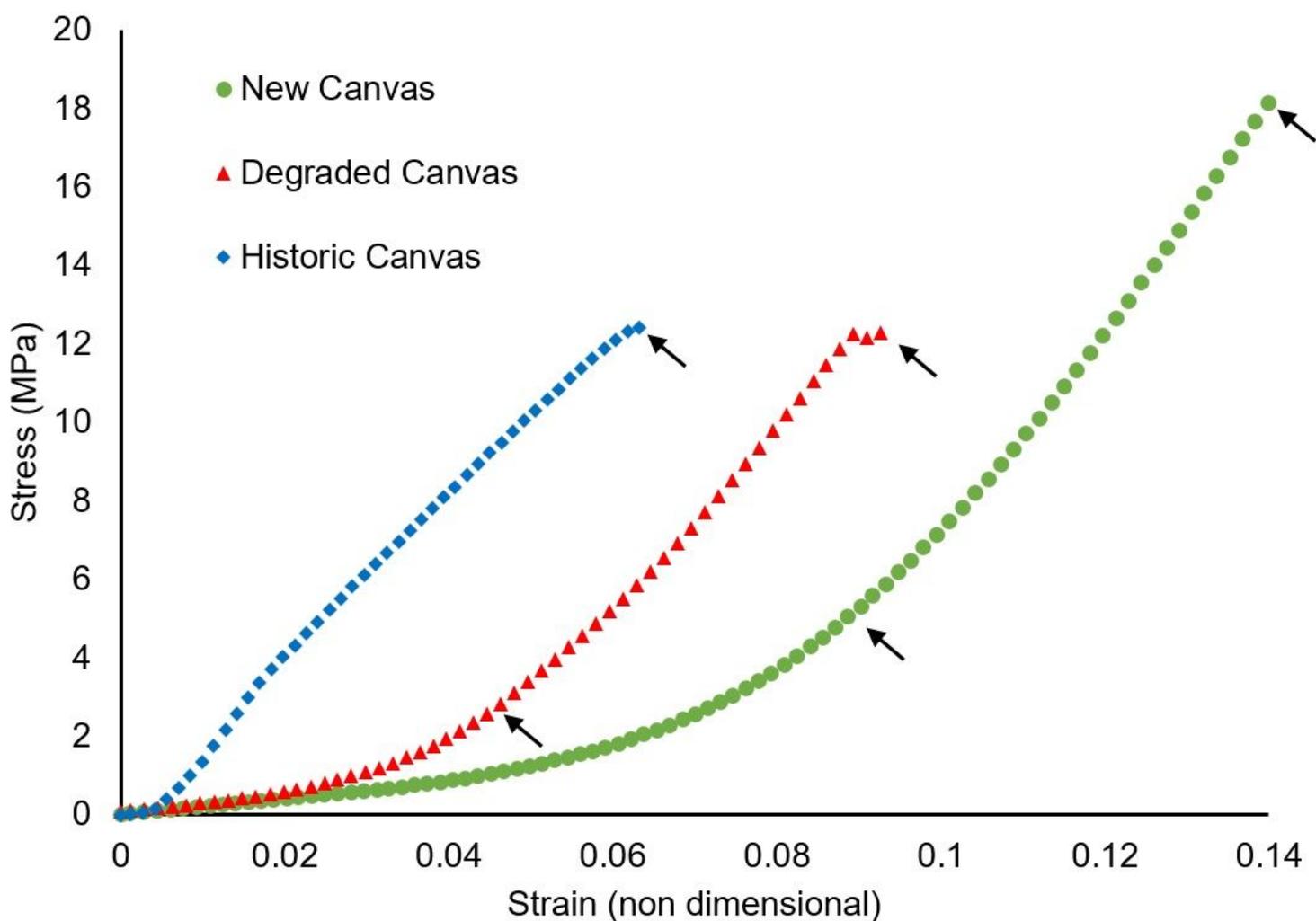


Figure 1

An example stress-strain plot for the three different types of canvas tested. The arrows indicate the start and end of regions of the curve, which can be quantified using the second tangent.

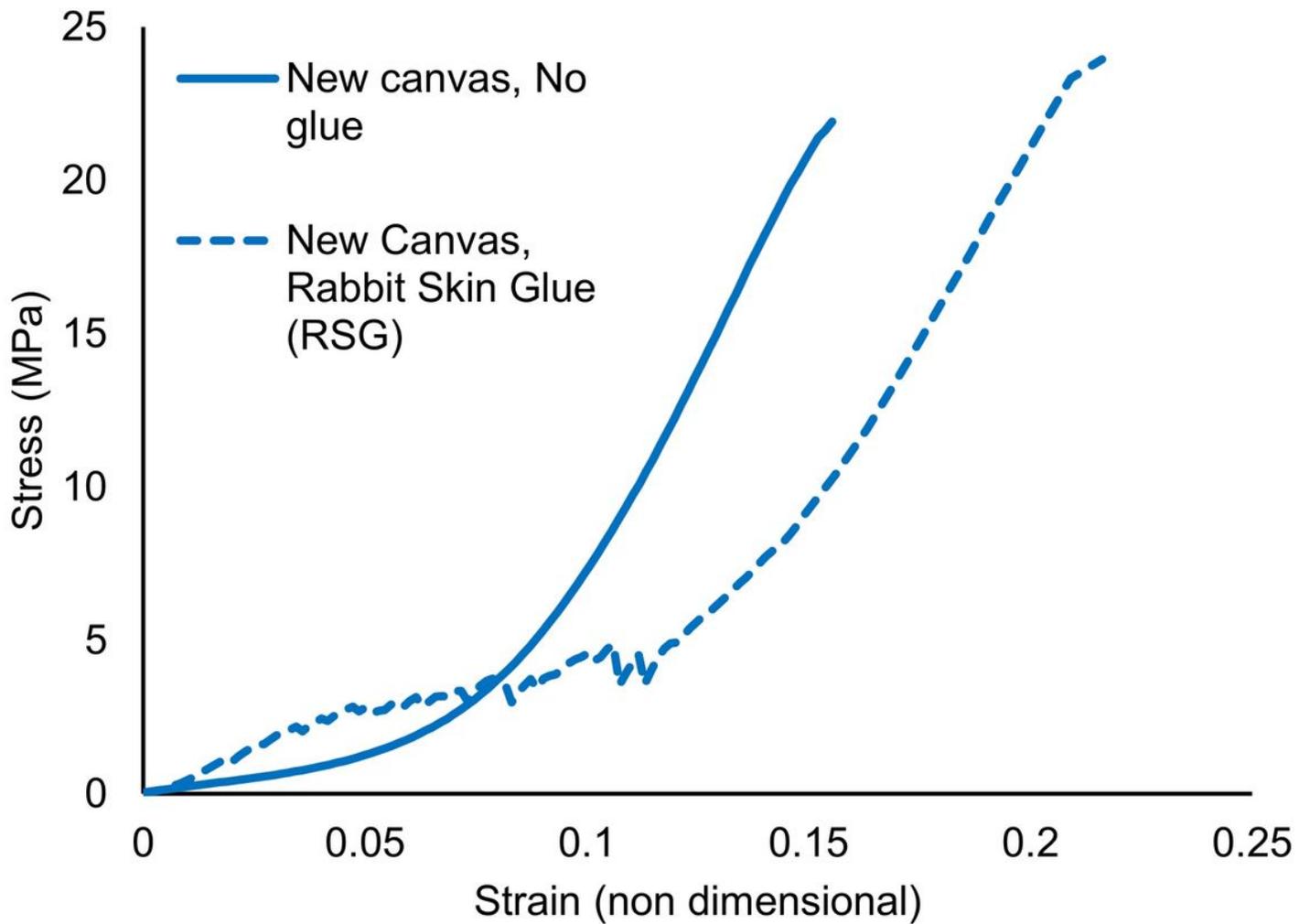


Figure 2

An example stress-strain plot of a new canvas with and without Rabbit Skin Glue (RSG).

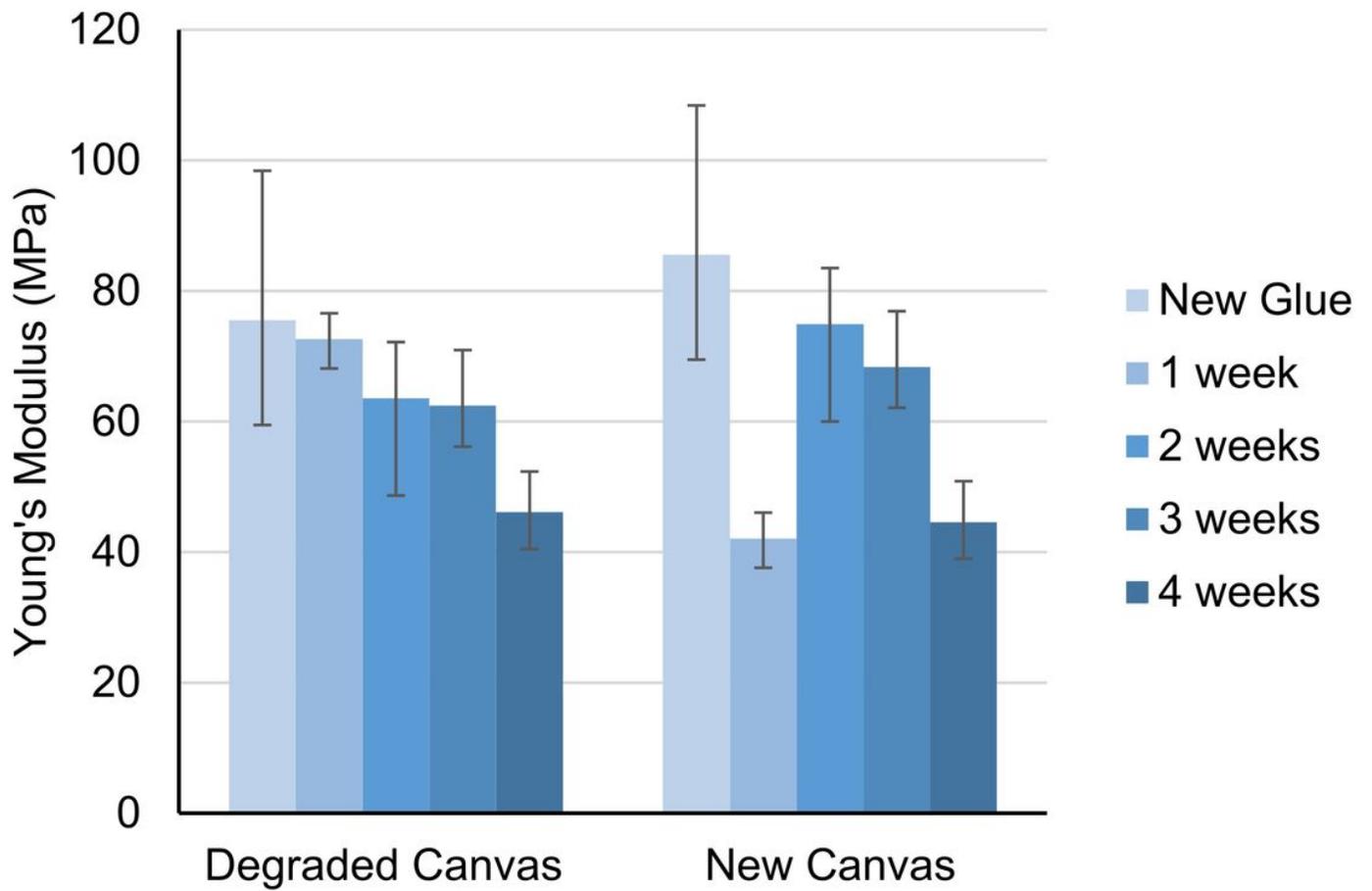


Figure 3

Comparison of the Young's Modulus (slope in the first region of the stress-strain curve) for Rabbit Skin Glue of varying ages applied to new and degraded canvas

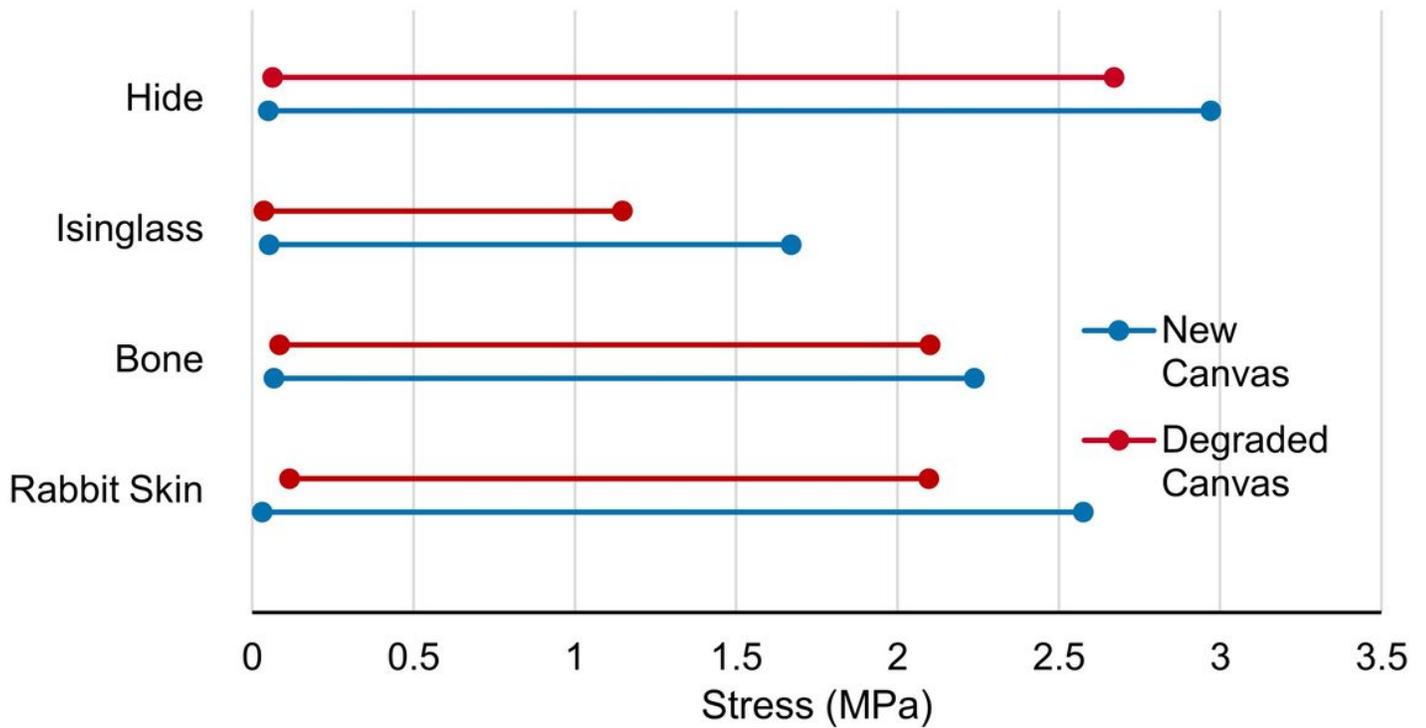


Figure 4

Comparison of the corresponding stress values for the first region of the stress-strain plot in the four different types of glues applied to both new and degraded canvas.

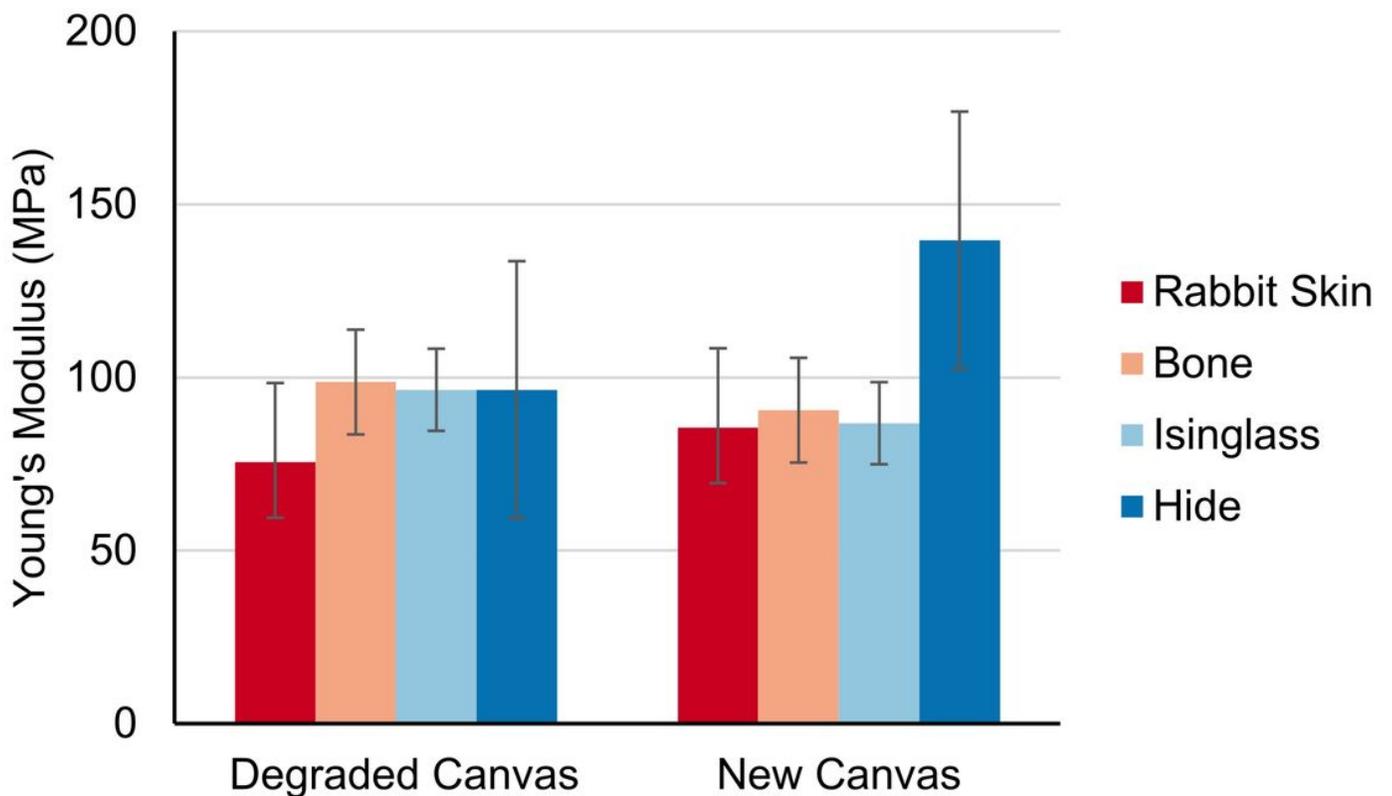


Figure 5

Comparison of the Young's Modulus calculated from the first region of the stress-strain plot of each of the 4 types of glue applied to new and degraded canvas.

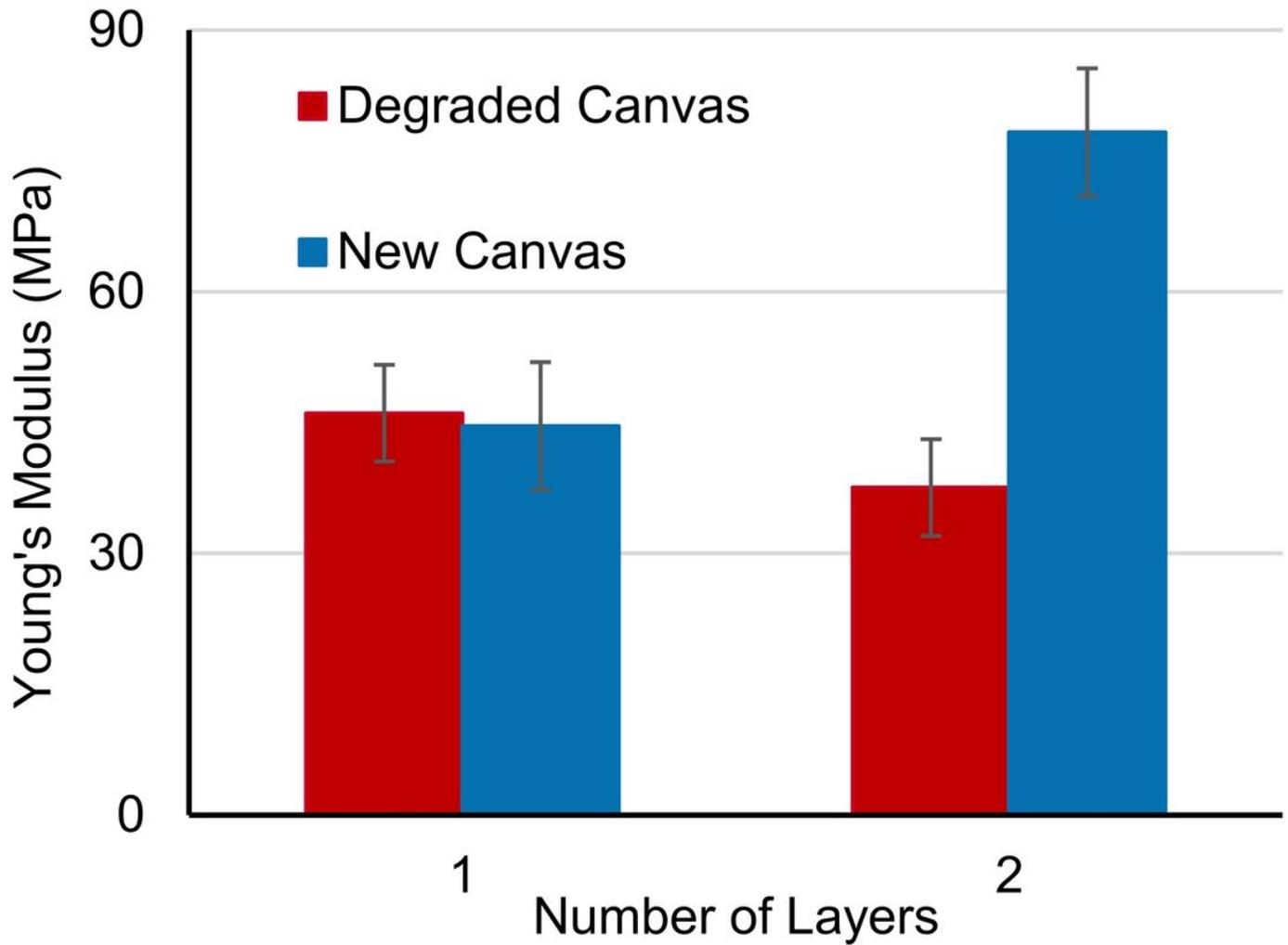


Figure 6

Young's Modulus for Rabbit Skin Glue, aged for four weeks and applied to new and degraded canvas in one and two layers.