EFFECT OF MOISTURE CONTENT OF THE WOOD AT THE TIME OF BONDING AND SUBSEQUENT TO BONDING ON GLUE JOINTS MADE WITH A COLD SETTING UREA-FORMALDEHYDE RESIN ADHESIVE.

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This report is submitted as partial fulfillment in candidacy for the degree of Master of Wood Technology.

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INTRODUCTION

Urea-formaldehyde resin adhesives were first introduced in 1937 as both hot press and low temperature setting adhesives.(1) The low temperature setting quality was a result of the development of chemical catalysts which replaced heat as the polymerizing agent. This development greatly furthered the use of the urea resin adhesives in industry, because it made it possible for factories not equipped with expensive hot presses to take advantage of the superior strength qualities of the resin adhesives.

It was also found that urea resins were easily extendable with various commercial extenders, and that the close technical control required when extending the phenolic type resin adhesives was not necessary to get strong uniform bonds. It is true that the durability of the bond is decreased as the ratio of the extender is increased, but even with high extension ratios, the durability is considerably better than that of natural glues. Also, the cost of the glue line decreases more rapidly as the extension is increased than does the quality of the bond.(1)

The combination of these two qualities of being cold setting and giving relatively inexpensive strong glue lines led to the conversion in many plants from the natural adhesives to cold setting urea resin adhesives.

As is often the case when a new material which appears superior to those already in use is introduced into industry, sufficient preliminary research is not conducted to bring to light all its various idiosyncrasies. Such was the case with cold setting urea-formaldehyde resin adhesives, and as a result, this lack of technical knowledge has in some instances proven extremely costly to industry. Recently, several concerns using cold setting urea resin adhesives in manufacturing multiply construction articles for home use, suffered serious economic setbacks as a result of delamination after the product had been in use for several months. The cause of this may lie in any one or in a combination of several of the factors which enter into the gluing procedure. While it is recognized that finding a single industrial cause for delamination which if corrected will erase such difficulties is next to impossible, it is felt that insufficient attention is being paid to the moisture content of the wood during manufacture in relation to the moisture content to which the product will be subjected in use.

It is a well known fact that with a change in moisture content wood will change in dimension varying amounts in the radial, tangential, and longitudinal directions. In multiply construction, alternate layers of veneer are laid with the grain directions running perpendicular to one another for the expressed purpose of controlling to a large extent dimensional changes due to a change in the moisture content of the wood. This restricting construction causes internal stresses to develop in the panel when changes in moisture content occur. If these changes in moisture content are sufficiently large so that the internal stresses developed are greater than the strength of the glue joint, the joint will rupture and delamination results.

This does not mean that a glue joint strong enough to counteract these internal stresses is the only criterion to obtaining an unruptured panel. It is possible with very strong glue joints for the stresses to be so great and the glue joints to be so unyielding as to rupture the face veneer or the face and crossbanding in tension.

It is apparent that one of the primary steps in controlling delamination is to reduce as much as possible the range of moisture content to which a piece is subjected. Without humidity control in one hundred per cent of the buildings, it is impossible to control the actual range of equilibrium moisture content within a building. In most of the United States this may vary from as low as 4% in winter to as high as 13% in summer while in the Southwest it remains very near 6% to 8% the year around and in the Southeast it remains very near 11% to 13% the year around.(2)

The only alternative is to keep the moisture content of the wood at the time of manufacture at the average moisture content to which it will be subjected, so that the maximum change in either direction will be as slight as possible. Yet, in industry it is quite common that exacting control of the moisture content of the wood previous to bonding and subsequent to bonding is not practiced. Without this technical control panels may be glued at 8%, matured at 4%, and then placed in homes where the moisture content reaches 13%. Such drastic changes in moisture content are certain to develop terrific internal stresses which will cause warping and delamination.

Also, at present there are no specifications concerning the equilibrium moisture content to which glued material should be subjected to obtain the maximum glue joint strength. According to the reports of the Madison Forest Products Laboratory, long exposure to high curing humidities gives weaker glue joints,(3) but Charles O. Swanson in his paper "Effect of Closed Assembly Time Below 70° F. on Plywood Panels Made with Room Temperature Setting Urea Resin Glues" presented at the University of Michigan in 1948, suggested that the reverse of this might be true, at least for short time maturing periods.

It is with these thoughts in mind of the relation between moisture content at the time of manufacture, curing moisture content, and the moisture content to which the product will be subjected in use that this work was carried out.

OBJECT

The object of this work is to determine the effect of moisture content of the wood at the time of bonding and subsequent to bonding on glue joints made with a cold setting urea-formaldehyde resin adhesive.

MATERIALS

1. 12" X 16" - 5/8" commercial core stock of indiscriminately glued yellow poplar, red gum, and soft maple.

2. 12" X 16" - 1/16" yellow poplar crossbanding.

3. 12" X 16" - 1/28" black walnut faces and backs.

4. Perkins L-100 cold setting urea-formaldehyde resin adhesive.

5. Perkins C-510 (winter) catalyst.

6. Soft wheat flour extender.

In the original draft of this project it was decided to use commercial material and commercial procedure whenever possible so as to approximate the existing conditions in industry. This is a very desirable practice as long as additional variables are not introduced. It was originally felt that the effect of regulating the moisture content of the wood previous to gluing would be sufficient to overshadow any other variables due to inequalities which naturally exist in commercial material. While this is the result which was hoped for, the writer now feels that in the first attempt to find the effect of a change in procedure upon the finished product, it is absolutely essential that as many of the factors as possible other than the one under observation be held constant. If such a procedure shows conclusively that the product is altered as a result of varying that one factor, then, and only then, should tests be made to determine whether the effect, which is now known to actually exist, is great enough to affect the quality of the product when produced with commercial material.

PROCEDURE

Conditioning of Material Prior to Bonding

The only requirement concerning the amount of material to be used was that there should be enough test specimens in each class so that the results could be considered representative of specimens glued under those particular conditions. Fifteen to twenty were considered to fulfill this requirement.

Four cores, eight sheets of crossbanding, and eight sheets of walnut for the faces and the backs were placed in each of three constant temperature humidity rooms which were maintained at equilibrium moisture contents of as near 4%, 8%, and 12% as was possible. The material was open piled to facilitate the free movement of air around and between each layer, so that after two weeks of exposure the moisture content of all pieces and within each piece would not vary.

All conditioning of the material prior to bonding and subsequent to bonding was done at approximately these three different conditions of equilibrium moisture content with the temperature held as nearly constant as was possible (80 to 85 deg. F.). 4%, 8% and 12% were the moisture contents chosen, but with the equipment available it was impossible to obtain these exact conditions. During the conditioning period the average moisture contents of each of the three rooms was 3.7%, 6.6%, and 12.8%. The fact that the exact desired moisture contents could not be maintained does not in any way alter the validity of the results because those values were only arbitrarily decided upon. 8% was chosen because it is within the optimum recommended for gluing with this adhesive while 4% and 12% were values well below and well above the recommended moisture content. Any other set of conditions filling the requirements of nearly optimum, above optimum, and below optimum would have been permissable to use.

Mixing of the Adhesive

In industry urea resin is very often used with considerable extension, so to approximate industrial conditions, extensions of 20% and 40% were used.

As nearly as possible, exactly the same sets of conditions were applied to specimens glued with each of the mixtures. These formulae are the same as were used by a concern which had great difficulties with delamination, as was mentioned in the introduction.

Proportions:

(a) 1. 100 gms. Perkins L-100 urea-formaldehyde resin.

2. 40 gms. soft wheat flour.

3. 40 gms. water.

4. 14 gms. C-510 catalyst (winter catalyst).

(b) 1. 100 gms. Perkins L-100 urea-formaldehyde resin.

2. 20 gms. soft wheat flour.

3. 20 gms. water.

4. 14 gms. C-510 catalyst (winter catalyst).

Sufficient adhesive was prepared to spread the material. The flour was added to the resin in the mixer and was mixed until free of all lumps. Using warm water to offset the chemical cooling action of the catalyst, the catalyst and water were mixed together, and then added to the resin and flour in the mixer. The entire batch was then thoroughly mixed to insure a homogeneous product. The working temperature at the time of mixing was 75 degrees F. which is well under the 80 degrees F.

recommended as maximum for this particular catalyst and resin. Higher mixing temperatures would tend to shorten the working life of the adhesive.(4)

Spreading of the Adhesive and Pressure Applied

When making shear tests to compare the glue joint strength as affected by certain variables, it is essential that the great majority of failures be glue line failures rather than wood failures. Wood failure does not give the comparative strength of the glue line, but rather the comparative tensile strength of the wood. For this reason a light single spread of 14 gms./sq. ft. of single surface (33 lbs./1000 sq. ft. of single surface) was used. Spreads of from 40 to 55 lbs./1000 sq. ft. of single surface are recommended for commercial use. The heavier spreads are for use on rough cut or porous surfaces or on unusually dry wood or when long assembly periods are used.(5)

A corrugated rubber roller glue spreading machine was used to insure an equal spread on all parts of the surface of the piece and on all pieces spread. The correct setting of the spreader rolls was determined by the following method.(6) Test pieces of veneer 1 ft. square were weighed to the nearest gram, and passed through the spreader, and weighed again. If the increase in weight was not the 28 grams (14 gms./sq. ft. single surface) which was desired, the spreader rolls were adjusted accordingly and another test piece was passed through. This was repeated until the correct glue spread was obtained. Care was also taken to be sure that the spread was equal on both surfaces. When the correct spread was obtained, the crossbanding only was spread (single spread), and the panels were assembled.

It would have been desirable to have had a nearly equal assembly time on all panels, but because of the lack of equipment it was necessary to spread and assemble all panels before pressing. Therefore, those which were spread first (the 20% extended formula) had a maximum of 25 minutes closed assembly, while those spread last (the 40% extended formula) had a maximum of 10 minutes closed assembly.

Immediately after the last panel was assembled, a pressure of 200 p.s.i. was applied to the stack. To compensate for glue squeezed out and compression of the wood, it was necessary to increase the load at frequent intervals during the first hour of the pressure period in order to maintain the pressure of 200 p.s.i. The pressure was maintained for 14 hours after which the panels were returned to their respective humidity rooms to mature before machining.

Preparation of Test Specimens

Eighteen hours after gluing, machining was begun to make standard plywood shear test specimens. Each panel was ripped so that a test specimen was obtained from both the face and the back side of the panel. Thus, the walnut face or back became one side of the specimen, the crossbanding became the core, and the part of the core stock ripped to the same thickness as the walnut became the other side.

Two pieces 9-1/2" along the face grain by 4" across the face grain (each piece representing 16 specimens) were cut from each of the six sets of panels (3 different moisture contents and 2 different extensions). These were used to note the effect on delamination of cumulative internal stresses due to changes in moisture content.

Conditioning Treatments Subsequent to Bonding

Specimens glued at each of the three moisture contents were subjected to varying periods of conditioning at each of those three moisture contents, and also to reversals of low and high moisture contents.

A system of notation was devised to accurately and conveniently record the history of each set of specimens. An example and explanation is shown below.

(example) 20-4-12-C

The "20" (first number) refers to the per cent extension which was either 20% or 40%.

The "4" (second number) refers to the moisture content at which the material was conditioned prior to bonding. This may be 4, 8, or 12. These approximate figures, rather than the actual moisture contents, were used to denote low, medium, or high moisture content respectively.

The "12" (third number) refers to the per cent moisture content at which the specimen was conditioned subsequent to bonding. This also may be 4, 8, or 12, and again denotes low, medium, and high rather than actual moisture content.

The letter "C" refers to the length and type of the conditioning period. This letter may be "A", "B", "C", or "D" according to the table below.

<u>From the 4% room</u>

A. Test after 2 weeks at 4%.

B. Test after 6 weeks at 4%.

C. Test after 2 weeks at 4%, 2 weeks at 12%, and 2 weeks at 4%.

<u>From the 8% room</u>

A. Test after 2 weeks at 8%.

B. Test after 6 weeks at 8%.

C. Test after 2 weeks at 8%, 2 weeks at 4%, and 2 weeks at 8%.

D. Test after 2 weeks at 8%, 2 weeks at 12%, and 2 weeks at 8%.

<u>From the 12% room</u>

A. Test after 2 weeks at 12%.

B. Test after 6 weeks at 12%.

C. Test after 2 weeks at 12%, 2 weeks at 4%, and 2 weeks at 12%.

At the end of the six week conditioning period the effect of the reversals was noted on the uncut pieces (9-1/2" X 4"). These were then cut up into standard plywood shear test specimens as was described under "Preparation of Test Specimens" and tested.

The two week tests were made to give an indication of the maximum strength attained by the joints. The six week tests without reversals were made to give any indication of deterioration due to the moisture content and the six week reversal tests were made to show the effect of cumulative stresses resulting from alternate expansion and contractions of the wood with changes in moisture content.

RESULTS

Delamination

Of the pieces left unsawed to show the effect of cumulative stresses only a few showed any degree of warping or delamination.

From the 4% room

Conditioning treatment C - The two pieces (extension 20% and 40%) glued at 4% warped and delaminated badly - the crossbanding separated from both the core and the face. Those glued at 8% and 12% were still in good condition.

From the 12% room

Conditioning treatment C - The two pieces (extensions 20% and 40%) glued at 4% warped quite badly and minor delamination had started at the ends. Those glued at 8% and 12% were still in good condition.

There was also delamination noted in one set of the test specimens which were machined and then conditioned. This occurred in the set glued with the 20% extended formula at 4% and subjected to a conditioning treatment of 12% for 6 weeks.

TABLE I

<u>Effect Of Wood Moisture Content At The Time Of Bonding On Glue Joint Strength Of Specimens Subjected To The Various Conditioning Treatments After Gluing</u>

20% Extension		
Moisture Content Glued At- Percent	Conditioning Treatment After Gluing	Glue Joint Strength In Ascending Order Of Shear Strength p.s.i.
6.6 3.7 12.8	4.1% for 2 wks. " " " " " "	173 189 Ave. - 184 191
6.6 3.7 12.8	4.1% for 6 wks. " " " " " "	183 192 Ave. - 194 206
3.7 12.8 6.6	4.1% for 2 wks., high for 2 wks., 4.1% for 2 wks.	148 157 Ave. - 156 162
3.7 6.6 12.8	6.7% for 2 wks. " " " " " "	197 205 Ave. - 215 243
3.7 6.6 12.8	6.7% for 6 wks. " " " " " "	193 207 Ave. - 205 215
3.7 6.6 12.8	6.7% for 2 wks., 4.1% for 2 wks., 6.7% for 2 wks.	186 205 Ave. - 202 215
12.8 3.7 6.6	6.7% for 2 wks., high for 2 wks., 6.7% for 2 wks.	139 151 Ave. - 156 177
3.7 6.6 12.8	13.4% for 2 wks. " " " " " "	203 225 Ave. - 237 283
3.7 6.6 12.8	high for 6 wks. " " " " " "	111 165 Ave. - 153 183

(TABLE I Continued on next page)

TABLE I (continued)

3.7 12.8 6.6	13.4% for 2 wks., 4.1% for 2 wks., 13.4% for 2 wks.	217 230 274	Ave. - 240
40% Extension			
12.8 3.7 6.6	4.1% for 2 wks. " " " " " "	189 207 219	Ave. - 205
12.8 6.6 3.7	4.1% for 2 wks. " " " " " "	196 204 209	Ave. - 202
12.8 3.7 6.6	4.1% for 2 wks., high for 2 wks., 4.1% for 2 wks.	151 153 169	Ave. - 158
12.8 3.7 6.6	6.7% for 2 wks. " " " " " "	222 225 260	Ave. - 236
3.7 12.8 6.6	6.7% for 6 wks. " " " " " "	214 218 241	Ave. - 224
3.7 12.8 6.6	6.7% for 2 wks., 4.1% for 2 wks., 6.7% for 2 wks.	215 218 233	Ave. - 222
12.8 3.7 6.6	6.7% for 2 wks., high for 2 wks., 6.7% for 2 wks.	155 166 169	Ave. - 163
3.7 12.8 6.6	13.4% for 2 wks. " " " " " "	235 268 311	Ave. - 271
6.6 3.7 12.8	high for 2 wks. " " " " " "	164 167 196	Ave. - 176
12.8 3.7 6.6	13.4% for 2 wks., 4.1% for 2 wks., 13.4% for 2 wks.	218 268 283	Ave. - 258

TABLE II

Effect Of Wood Moisture Content At The Time Of Bonding On The Maximum Glue Joint Strength Attained By Specimens Subjected To The Various Moisture Contents Of The Two Week Conditioning Period

20% Extension			
Moisture Content Glued At-Percent	Conditioning Treatment After Gluing	Glue Joint Strength In Ascending Order Of Shear Strength-p.s.i.	
6.6	4.1% for 2 wks.	173	
3.7	" " "	189	Ave. - 184
12.8	" " "	191	
3.7	6.7% for 2 wks.	197	
6.6	" " "	205	Ave. - 215
12.8	" " "	243	
3.7	13.4% for 2 wks.	203	
6.6	" " "	225	Ave. - 237
12.8	" " "	283	
40% Extension			
12.8	4.1% for 2 wks.	189	
3.7	" " "	207	Ave. - 205
6.6	" " "	219	
12.8	6.7% for 2 wks.	222	
3.7	" " "	225	Ave. - 236
6.6	" " "	260	
3.7	13.4% for 2 wks.	235	
12.8	" " "	268	Ave. - 271
6.6	" " "	311	

TABLE III

Effect Of Moisture Content During The Conditioning Period Subsequent To Bonding On The Maximum Glue Joint Strength Attained By Specimens Glued At Three Different Moisture Contents

Conditioning Treatment After Gluing	Moisture Content Glued At-Percent	Glue Joint Strength in Ascending Order Of Shear Strength-p.s.i.	
20% Extension			
4.1% for 2 wks.	3.7	189	
6.7% for 2 wks.	"	197	Ave. - 196
13.4% for 2 wks.	"	203	
4.1% for 2 wks.	6.6	173	
6.7% for 2 wks.	"	205	Ave. - 201
13.4% for 2 wks.	"	225	
4.1% for 2 wks.	12.8	191	
6.7% for 2 wks.	"	243	Ave. - 239
13.4% for 2 wks.	"	283	
40% Extension			
4.1% for 2 wks.	3.7	207	
6.7% for 2 wks.	"	225	Ave. - 222
13.4% for 2 wks.	"	235	
4.1% for 2 wks.	6.6	219	
6.7% for 2 wks.	"	260	Ave. - 263
13.4% for 2 wks.	"	311	
4.1% for 2 wks.	12.8	189	
6.7% for 2 wks.	"	222	Ave. - 226
13.4% for 2 wks.	"	268	

Effect Of Moisture Content During The Conditioning Period Subsequent To Bonding On The Maximum Glue Joint Strength Attained By Specimens Glued At Three Different Moisture Contents

20% Extension

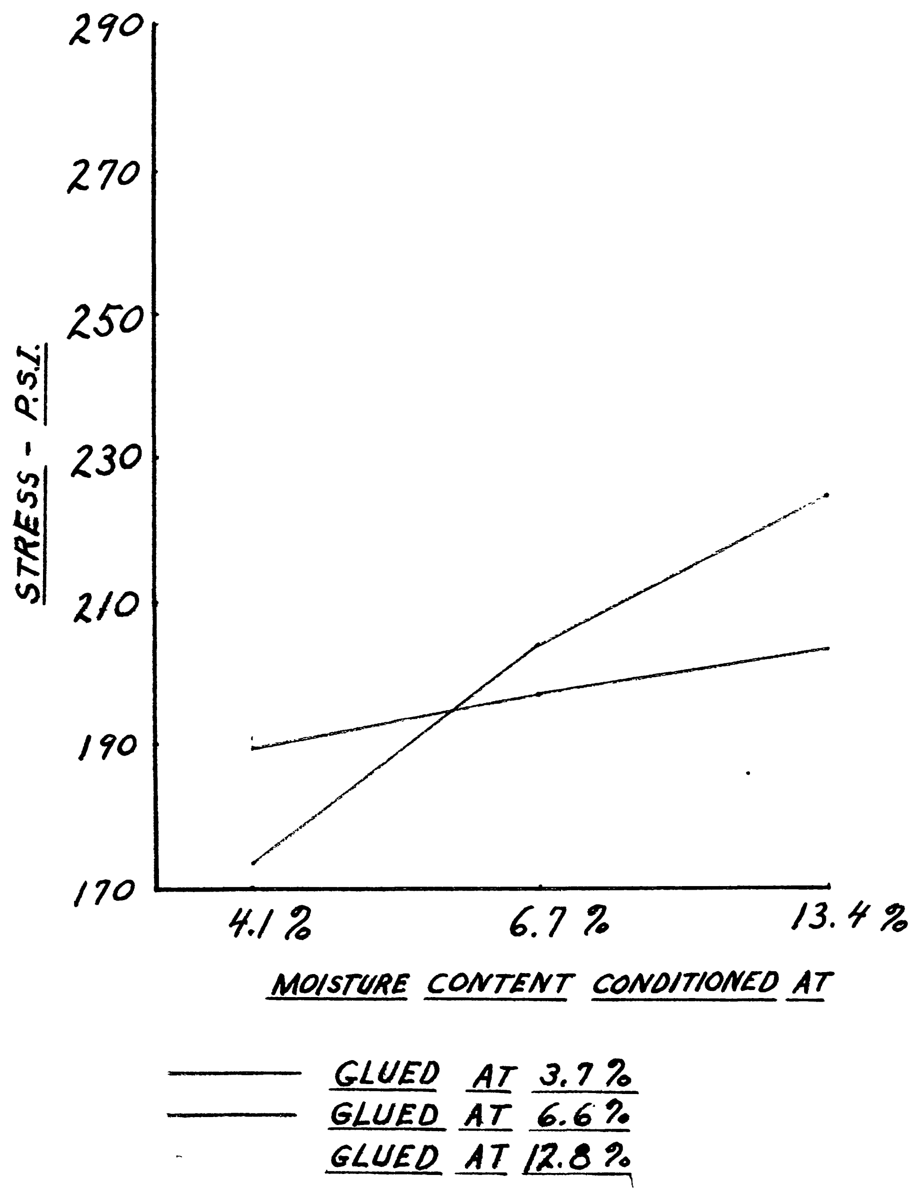

Fig. 1.

Effect Of Moisture Content During The Conditioning Period Subsequent To Bonding On The Maximum Glue Joint Strength Attained By Specimens Glued At Three Different Moisture Contents

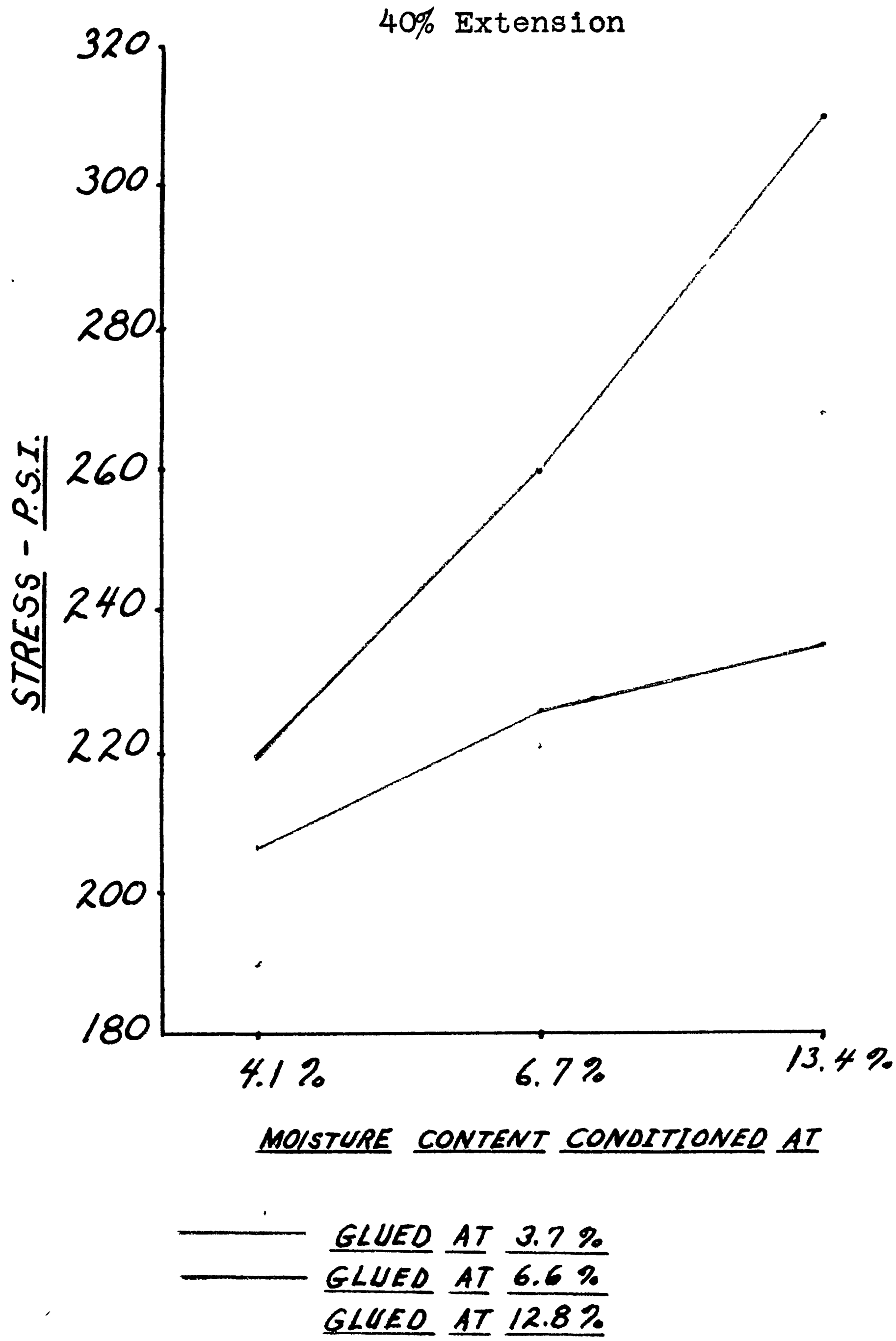

Fig. 2.

DISCUSSION OF RESULTS

Upon examining the results, the most noticeable indication is that the 40% extended formula gave consistently higher strength values than did the 20 % extension. This is contrary to previous technical knowledge which states that with the same bonding conditions, a 20% to 35% extension will give maximum strength results.(7) Lower extensions cause too rapid penetration into the wood the strength of higher extensions is affected by the increasing amount of a material which has little adhesive properties. The durability of the bond decreases with increased extension. It is believed that the greater strength of the higher extension shown in this work is due to one or more differences in the bonding procedure.

Only one such variation in the bonding procedure is noted. That is the assembly time. It was necessary because of lack of time and equipment to mix and spread both extensions during the same period. It is known that assembly time decreases with the age of the mixed adhesive. The 40% extension was mixed first, so to be considerate of its shorter assembly time, it was spread last. This gave a maximum assembly time of 10 minutes for the 40% extension which is well within specifications and 25 minutes for the 20% which is the maximum allowable time for that extension.(4) Very thin spreads reduce the assembly time, so it is possible that by the time the pressure was applied the adhesive began losing its tackyness, and therefore, the resulting joint strength was reduced. Had skilled glue spreader operators been available, the assembly times could have both been well within specifications in which case the differences would not have been of importance. The actual spreading of the two batches took only a few minutes, but between the first spreading and the second it was necessary to open the rolls, remove all the adhesive, and then close and readjust the rolls to give the proper spread. Thus the large difference in assembly time.

Considering the above discussion it is evident that comparisons of any kind should not be made between the results obtained for the two different extensions. Each must be considered as a separate set of results.

Examination of Table II and Table III shows a very important relationship concerning the moisture content the panel is subjected to during the maturing period. In this work the average per cent moisture content of the rooms during the two week maturing period was 4.15 for the low, 6.7 for the medium, and 13.4 for the high with maximums and minimums of 3.7 and 4.6, 6.6 and 6.8, and 12.8 and 14.0 respectively.

At the end of the pressure period only about 50% of the final joint strength is attained, therefore, a maturing period is needed so that sufficient strength will be developed in the glue joint so as not to be ruptured by the stresses of machining.

In all the present literature giving maturing period specifications no mention whatsoever is made of the equilibrium moisture content of the maturing room. Temperature is the only condition considered important and that only as it affects the length of time before machining is allowed, rather than as affecting the maximum strength of the bond.

These results definitely show that variation in the moisture content of the conditioning room is extremely important in determining the final strength of the glue joint regardless of the gluing conditions. Table II shows conclusively that for both extensions the average of the strengths obtained by gluing at the three moisture contents increases as the moisture content of the maturing room is increased. Table III very definitely shows that without exception the strength of the joints glued at the three different moisture contents increases as the moisture content of the maturing condition is increased. This is more clearly shown in Fig. 1 and Fig. 2 by the graphical representation of Table III.

This does not mean, however, that further increase in moisture content of the maturing room will give a further increase in the strength of the bond. It is noted that delamination occurred in one set of the machined specimens that were subjected to the high moisture content for 6 weeks. One of the properties of unfortified urea resin adhesives, especially if extended, is that they are deteriorated by long exposure to high humidities. At one time during the experiment it was necessary to leave the humidity room unattended for a period of one week. The controls in the high humidity room were such that by the end of that period the equilibrium moisture content had risen to 17.2%. The only group that showed any delamination was that which was glued at 4 % with the 20% extended formula. However, all those which were subjected to that week of extra high humidities showed a substantial loss of strength (the six sets left for six weeks at 12% - the six sets left at 4% for 2 weeks, 12% for 2 weeks, and 4% for 2 weeks - the six sets left at 8% for 2 weeks, 12% for 2 weeks, and 8% for 2 weeks). Therefore, there is a maximum moisture content to which a glue bond may be subjected and still give an increase in strength.

In addition to the above discussion the results give further support to the indication that a relatively high moisture content conditioning treatment subsequent to bonding will increase the strength of the glue joint. Table I shows that high joint strength was obtained for even those specimens which were subjected to such rigorous reversals as from 4% back up to 12% after first having a two week conditioning period at 12%. It is regrettable that the high moisture content room got out of hand for that short period causing a definite deterioration of the bonds. It would have been enlightening to compare the results of the 12%- 4%- 12% reversals with the 4%- 12%- 4% reversals.

The results apparently do not substantiate the original contention that bonding material which is at approximately the same moisture content as that which it will be subjected to in service will give the strongest glue joints. Table III and Fig. 1 and Fig. 2 show without question that of the specimens glued at each moisture content those which were subjected to the high moisture content subsequent to bonding gave the strongest joints. However, it is shown that gluing at the higher moisture contents gives the stronger bonds. This is in agreement with present published specifications.(4) (5)

The consideration of Table III alone does not give the complete information about gluing material of a moisture content which will approximate that to which it will be subjected in use. It is still contended that more attention should be paid to gluing at a moisture content which will be the average of the conditions to which the piece will be exposed in use. That this is a valid statement is very clearly shown in the results of 12% - 4% - 12% and the 4% - 12% - 4% reversals of moisture content as shown in Table I. In each case the highest strength values were obtained by those specimens which were glued at 8%.

Even though the results of the 4% - 12% - 4% reversal treatment are inaccurate because of the accidental exposure to such a very high moisture content, the results can still be used for comparison of the sets within that group because they were all subjected to the same condition.

Actual glue joint strength is not the only criterion as to the quality of a bonded panel. It must also be as dimensionally stable as possible. It was noted that of the material exposed to the 12% - 4% - 12% moisture content reversals, the panels glued with material at 4% warped badly and had slight indications of delamination. Those glued at 8% and 12% were still in good condition. Also, of those panels exposed to the 4% - 12% - 4% moisture content reversals, the ones glued at 4% showed considerable delamination and warping while those glued at 8% and 12% were still good. It might be expected that because they would undergo the same wide range of moisture content as those glued at 4% the panels glued at 12% would also delaminate and warp, but the glue joint strength of those was sufficient to overcome the stresses developed, so they remained sound.

CONCLUSIONS

Several factors which may lead to better methods of gluing procedure have been brought to light by this work. They vary from simply bearing out the findings of previous research to pointing the way to further research on entirely new procedures.

It is of interest to note that these results are in agreement with existing specifications on moisture contents of material prior to gluing with cold setting urea-formaldehyde resin adhesives.(4) (5) From 8% to 12% was found to give the strongest bonds, but this statement is tempered somewhat by the findings concerning the effect of moisture consent on the glue joint subsequent to bonding.

It was found that in this work exposure of the bond to high moisture contents of approximately 13% during the maturing period regardless of the moisture content of the material when glued gave considerably higher strength values than did exposure to the lower moisture contents. It remains to be determined just how high a moisture content can be used to increase the strength of the bond without causing deterioration with age. Also it remains to find the length of time needed at these high humidities to reach the maximum strength of the joint. It must be kept in mind too that when using high curing humidities the tendency of the piece to warp is increased, and also any effect of the higher moisture contents on finishing problems must be considered.

These results show that if cured at a high humidity the strength of the bond remains very high even if subjected to very low humidities. However, exposure to these wide ranges of moisture content will build up high internal stresses and the tendency for the piece to warp is increased.

Considering the results of this work it is indicated that the best bonded panel (one having very high glue joint strength while showing little tendency to warp at the average moisture content changes which occur in homes in the middle west) may be obtained by bonding material which is at 10% moisture content and by subjecting that bonded panel to a maturing moisture content of 10%. A slightly higher conditioning moisture content would probably give a stronger glue joint, but it would also increase the tendency for the panel to be unstable.

Further research into this recommended procedure may prove that panels can be produced which will have stronger glue joints and which will be more stress free than those which are manufactured today. Combining these two factors of increased strength and lowered internal stresses will do much to reduce the present problems concerning warping and delamination.

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