# STIFFNESS COEFFICIENTS IN JOINTS BY STAPLES OF SKELETON UPHOLSTERED FURNITURE

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## ABSTRACT

The presented study is the result of a laboratory testing under bending stress by collecting arms by corner butt joints with 2 staples type M1/40 of Scots pine (Pinus sylvestris L.) members and boards (OSB, PB, PW) to determine the deformation behaviour of the joints.

The aim of the study is to establish the stiffness coefficients by examining the influence of the material, the reinforcement by means of a triangular wood member and the type of joints on the deformation behaviour of butt joints by staples.

The results obtained could be used as a basis for future research to predict the deformation behaviour of furniture constructions as well as to find their application in the design of skeletons of upholstered furniture.

**Key words:** upholstered furniture, end corner joints, staple joints, stiffness coefficients.

## INTRODUCTION

In recent years, in the manufacture of skeletons of upholstered furniture, butt joints by staples are increasingly being used. This is dictated by the high productivity and less labor intensity in the technological operations compared to the other non-detachable joints used in the constructions of upholstered furniture (skeletons). In practice, when building the skeletons of upholstered furniture, butt joints by staples and reinforcing members are successfully applied.

The first person who researched this type of joints is Eckelman, whose publications date back to 1971. In them the author determines the bending strength and stiffness of middle corner joints of plywood members from Douglas fir (*Pceudotsuga*). It has been found that in the presence of a single-sided reinforcing member a satisfactory strength is provided for that can be improved by increasing the size of the reinforcing member. It is also concluded that the strength depends directly on the shear strength of the adhesive joint of the individual veneer sheets of the plywood rather than on the number and density of the staples (Eckelman, 1971). The reinforcing members can also be made of High Density Fibreboard (HDF). Such joints are subjected to a study by Erdil et al. (2003). They determined the maximum bending moment of middle corner joints by staples, means of OSB members and HDF reinforcing member with and without the presence of adhesive. The results indicate that the application of glue results in a double increase in the strength of the joints.

In the specialised literature, there are publications whose subject of study is middle corner joints of staples by means on OSB members with reinforcing members with or without application of glue with polyvinyl acetate adhesive. The joints are subjected to static bending. In consequence of the results obtained, the authors conclude that, in the presence of application of glue on the reinforcing members, the strength is increased by 27%. It is also concluded that a reinforcing member with a length of 102 mm is insufficient and such one with a length of 305 mm is resized for such a type of joints. It has been found that increasing the width of the reinforcing member in the range from 102 mm to 203 mm, in the presence and absence of adhesive, is not a prerequisite for greater strength of the joint. The authors conclude that changing the position of the staple does not affect the strength of the joint (Wang et al., 2007[a]). In the second part of his study, Wang et al. examine the behaviour of the same type of joints under dynamic load. The results show that even in the presence of different types of destruction in both types of joints, with or without adhesive, the ratio between static to dynamic maximum load force is preserved. In the case of staple joints, the high value of the ratio is due to the pulling of the staple. In the case of adhesive joints, the low value of the ratio results from a shear along the thickness of the board and the high due to breaking of the member of the joint. In conclusion of their study, the authors conclude that such type of joints should not be subjected to load with more than 48% of the breaking force obtained under a static load (Wang et.al., 2007[b]).

In the literature, data has been found to determine bending and tensile strength of corner joints by staples by means on wood members of beech (*Fagus sylvatica*) and poplar (*Populus sp.*). The joints are reinforced with a member in the form of a triangular block or two-sided member of HDF (Kamperidou et al., 2010). The values determined for the maximum bending moments are the lowest for joints with double reinforcing member. Based on the results obtained, the authors conclude that the type of wood does not significantly affect the values of the maximum strength of the joint.

Bulgarian scientists determine the maximum bending moments under bending load with bringing together and opening of the arms of the end corner joints by smoothing and joints at 90-degree angle and at 45-degree angle of the wood members of spruce (*Picea abies* Karst.). The authors recommend that the standard values of the maximum bending moments be used as the control in determining the quality of the furniture constructions (Kyuchukov et.al, 2015).

The aim of the study is to determine the stiffness coefficients by examining the influence of the material, the reinforcement by means of a triangular wood member and type of joints on the deformation behaviour of butt joints by staples.

## MATERIALS AND METHODS

For the purposes of the present study, test samples were made with wood members of Scots pine (*Pinus sylvestris* L.) with a cross-section of 25/50 mm and board members of Oriented Strand Board (OSB) with a thickness of 15 mm, Particle board (PB) with a thickness of 16 mm and plywood of birch (PW) with a thickness of 15 mm. The members were assembled with two staples $M_{1/40}$ and polyvinyl acetate adhesive (PVA) adhesive.

The materials have the following physical and mechanical properties:

- Scots pine (*Pinus sylvestris* L.) with a density of $\rho = 430$ k.m$^{-3}$, modulus of elasticity – $E_{L12\%} = 9000.10^6$ N.m$^{-2}$, $E_{R12\%} = 593.10^6$ N.m$^{-2}$ and bending strength $\sigma_{bend.12} = 65.10^6$ N.m$^{-2}$;
- OSB – $\rho$= 596 kg.m$^{-3}$, $E_{\parallel} = 3500.\ 10^6$ N.m$^{-2}$, $E_{\perp} = 1400.\ 10^6$ N.m$^{-2}$, $\sigma_{bend.\parallel} = 20.\ 10^6$ N.m$^{-2}$, $\sigma_{bend.\perp} = 10.\ 10^6$ N.m$^{-2}$;
- PB – $\rho$ = 678 kg/m$^3$, $E_{\parallel} = 1600.\ 10^6$ N/m$^2$, $E_{\perp} = 2750.\ 10^6$ N.m$^{-2}$, $\sigma_{bend.\parallel} = 11.\ 10^6$ N.m$^{-2}$, $\sigma_{bend.\perp} = 8\ .\ 10^6$ N.m$^{-2}$;
- PW – $\rho$ = 629 kg/m$^3$, $E_{\parallel} = 7224.\ 10^6$ N.m$^{-2}$, $E_{\perp} = 5709.\ 10^6$ N.m$^{-2}$, $\sigma_{bend.\parallel} = 61.\ 10^6$ N.m$^{-2}$, $\sigma_{bend.\perp} = 57.\ 10^6$ N.m$^{-2}$.

For this were used staples of the company “SANCOSAN” series 100, type M1 with a length of 40 mm and a wire cross-section of 1,24 x 1,46 mm and a PVA adhesive of the company HENKEL – “Moment Wood Standard“, water resistance class D2, consumption 100÷200 g.m$^{-2}$, viscosity $\eta$ = 8000÷15000 m.Pas and open time t=8 min.

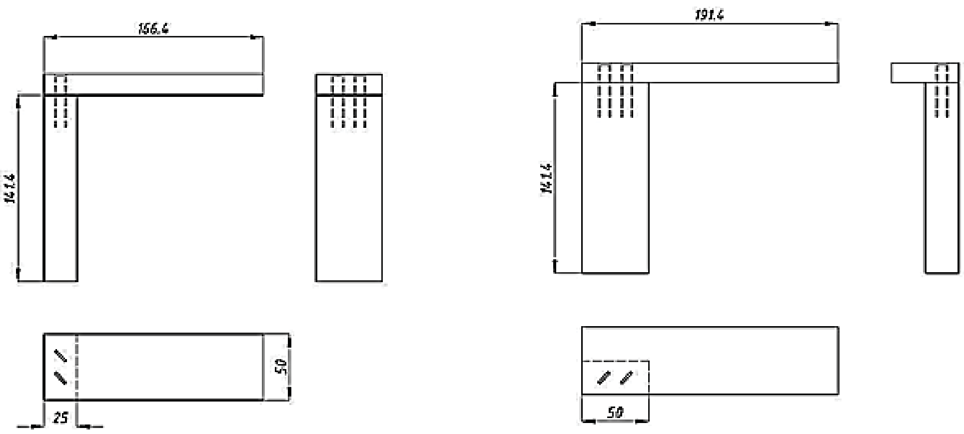
The type of test samples is listed in table 1, respectively, of the form and dimensions shown in Fig. 1.

**Table 1: Type of end corner butt joint with two staples $M_{1/40}$ of parts from Scots pine (*Pinus sylvestris* L.) and boards**

| Type of end corner butt joints with 2 staples $M_{1/40}$ | Materials | | |
|---|---|---|---|
| | Parts from Scots pine and OSB | Parts from Scots pine and PB | Parts from Scots pine and PW |
| Case butt joint with 2 staples and PVA | $CE_{1M1/40PVA}$ 21* | $CA_{1M1/40PVA}$ 25 | $CD_{1M1/40PVA}$ 29 |
| Case butt joint with 2 staples, PVA and corner block | $CE_{1M1/40\Delta PVA}$ 22 | $CA_{1M1/40\Delta PVA}$ 26 | $CD_{1M1/40\Delta PVA}$ 30 |
| End-to-face butt joint with 2 staples and PVA | $CE_{2M1/40PVA}$ 23 | $CA_{2M1/40PVA}$ 27 | $CD_{2M1/40PVA}$ 31 |
| End-to-face butt joint with 2 staples, PVA and corner block | $CE_{2M1/40\Delta PVA}$ 24 | $CA_{2M1/40\Delta PVA}$ 28 | $CD_{2M1/40\Delta PVA}$ 32 |

** 21 – number series*

$CE_{1M1/40PVA}$, $CA_{1M1/40PVA}$, $CD_{1M1/40PVA}$ $CE_{2M1/40\Delta PVA}$, $CA_{2M1/40\Delta PVA}$, $CD_{2M1/40\Delta PVA}$




$CE_{1M1/40PVA}$ , $CA_{1M1/40PVA}$, $CD_{1M1/40PVA}$ $CE_{2M1/40\Delta PVA}$ , $CA_{2M1/40\Delta PVA}$, $CD_{2M1/40\Delta PVA}$

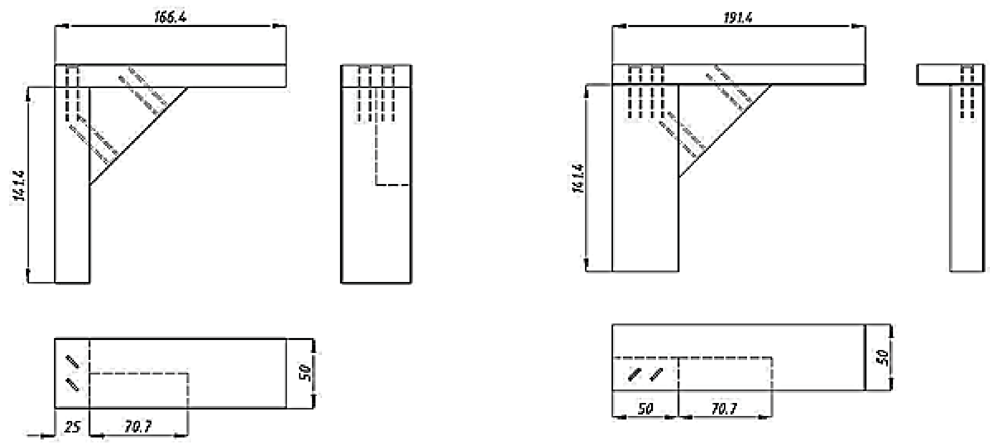



**Figure 1: Type and dimension of the tested samples**

For determining the stiffness coefficients, the test samples were subjected to a bending load by collecting arms, using a simultaneous testing method of the strength and deformation characteristics of the fixed corner joints of members and board construction members of furniture under bending load (Kyuchukov et.al, 2016).

The stiffness coefficient $c_i$ under bending stress by collecting arms was determined according to formula 1 in N.m.rad$^{-1}$.

$$c_i = \frac{\Delta M_i}{\Delta \alpha_i}, \quad (1)$$

$$\Delta M_i = M_i - M_0 \quad (2)$$

$$\Delta \alpha_i = \alpha_i - \alpha_0 \quad (3)$$

Where $c_i$ is rotational stiffness, N.m.rad$^{-1}$;

$M_i, M_0$ – bending moment for $F_{40}$ and $F_{10}$, N.m;

$\alpha_i, \alpha_0$ – angle of semi-rigid rotation of the arms of the joint at $F_{40}$ and $F_{10}$, rad.

All the data are statistically processed and the Student t-distribution was established.

## RESULTS AND DISCUSSION

In Table 2 and in Fig. 2 are presented the average values of the stiffness coefficients.

**Table 2: Variation statistics parameters from stiffness coefficients of end corner butt joints with 2 staples $M_{1/40}$ of parts from Scots pine (*Pinus sylvestris* L.) and furniture plates under bending**

| № series | Type of joint | Stiffness coefficients, c [N.m.rad$^{-1}$] | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Variation statistics parameters | | | | | | | |
| | | $\overline{\chi}$ [N.m.rad$^{-1}$] | $c_{max.}$ [N.m.rad$^{-1}$] | $c_{min.}$ [N.m.rad$^{-1}$] | med. [N.m.rad$^{-1}$] | s [N.m.rad$^{-1}$] | v [%] | p [%] | n [pc.] |
| 21 | $CE_{1M1/40PVA}$ | 1482,07 | 2006,55 | 1323,60 | 1437,72 | 210,16 | 14,18 | 4,73 | 9 |
| 22 | $CE_{1M1/40\Delta PVA}$ | 2623,89 | 3259,77 | 1956,91 | 2638,78 | 369,65 | 14,01 | 4,70 | 9 |
| 23 | $CE_{2M1/40PVA}$ | 844,21 | 960,13 | 733,13 | 796,22 | 96,11 | 11,39 | 3,80 | 9 |
| 24 | $CE_{2M1/40\Delta PVA}$ | 1813,08 | 1942,57 | 1655,62 | 1841,78 | 96,03 | 5,30 | 1,77 | 9 |
| 25 | $CA_{1M1/40PVA}$ | 1017,52 | 1090,64 | 760,38 | 1052,25 | 102,86 | 10,11 | 3,20 | 10 |
| 26 | $CA_{1M1/40\Delta PVA}$ | 2233,93 | 2474,34 | 1966,22 | 2250,21 | 174,84 | 7,83 | 2,48 | 10 |
| 27 | $CA_{2M1/40PVA}$ | 822,77 | 1038,85 | 651,17 | 829,79 | 111,45 | 13,55 | 4,28 | 10 |
| 28 | $CA_{2M1/40\Delta PVA}$ | 1192,05 | 1471,00 | 1015,46 | 1141,30 | 153,45 | 12,87 | 4,07 | 10 |
| 29 | $CD_{1M1/40PVA}$ | 1788,18 | 2217,31 | 1158,32 | 1843,52 | 300,21 | 16,79 | 4,85 | 12 |
| 30 | $CD_{1M1/40\Delta PVA}$ | 3228,00 | 3720,45 | 2465,46 | 3428,73 | 427,08 | 13,23 | 4,68 | 8 |
| 31 | $CD_{2M1/40PVA}$ | 1432,69 | 1727,74 | 1075,18 | 1371,13 | 192,55 | 13,44 | 4,25 | 10 |
| 32 | $CD_{2M1/40\Delta PVA}$ | 3878,37 | 4524,52 | 2894,20 | 3905,40 | 566,43 | 14,60 | 5,52 | 7 |

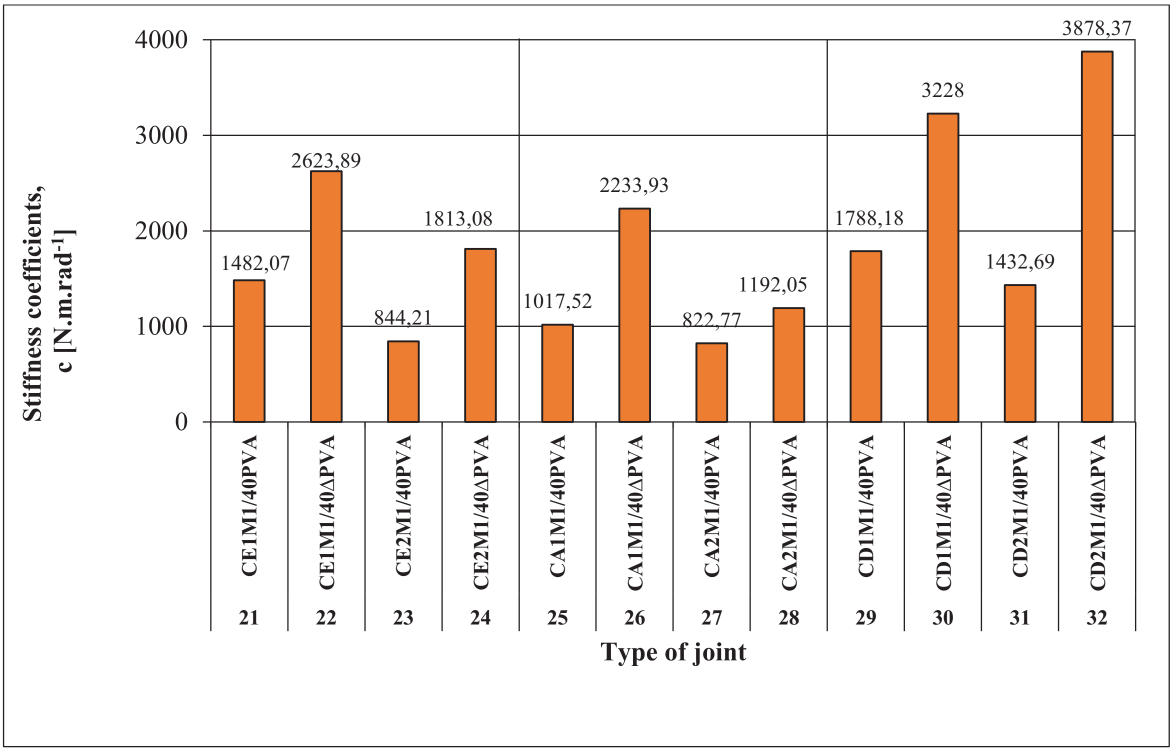



**Figure 2: Stiffness coefficients**

The largest value of the tested series of joints of members of pine and furniture boards is 3878,37 N.m.rad$^{-1}$, found in end-to-face butt joints with reinforcing member of pine and PW members ($CD_{2M1/40\Delta PVA}$), and the smallest of 822,77 N.m.rad$^{-1}$ at end-to-face butt joints of pine and PB members ($CA_{2M1/40PVA}$). The percentage difference between the largest and the smallest value is 78,78% ($t_{calc.}$ 2,45>$t_{tab.}$ 14,08).

The reinforcement of joints with triangular wood member increases the values of the stiffness coefficients of the tested series of joints, with significant percentage differences respectively: 43,52% ($t_{calc.}$2,16>$t_{tab.}$8,06) at $CE_{1M1/40PVA}$ and $CE_{1M1/40\Delta PVA}$; 53,44% ($t_{calc.}$2,11>$t_{tab.}$21,39) at $CE_{2M1/40PVA}$ and $CE_{2M1/40\Delta PVA}$; 54,45% ($t_{calc.}$2,13>$t_{tab.}$18,96) at $CA_{1M1/40PVA}$ and $CA_{1M1/40\Delta PVA}$; 30,98% ($t_{calc.}$2,12>$t_{tab.}$6,16) at $CA_{2M1/40PVA}$ and $CA_{2M1/40\Delta PVA}$; 44,60% ($t_{calc.}$2,14>$t_{tab.}$8,58) at joints $CD_{1M1/40PVA}$ and $CD_{1M1/40\Delta PVA}$; 63,06% ($t_{calc.}$2,18>$t_{tab.}$12,33) at $CD_{2M1/40PVA}$ and $CD_{1M1/40\Delta PVA}$.

The stiffness coefficients is higher values in case butt joints compared to those end-to-face butt joints with the exception of joints with a reinforcing member of pine and PW members ($CD_{1M1/40\Delta PVA}$ and $CD_{2M1/40\Delta PVA}$) where the differences for the series of joints were with established feedback. The specified percentage differences for the series of joints are as follows, where: $CE_{1M1/40PVA}$ and $CE_{2M1/40PVA}$ – 43,04% ($t_{calc.}$2,20<$t_{tab.}$8,28); $CE_{1M1/40\Delta PVA}$ и $CE_{2M1/40\Delta PVA}$ – 30,90% ($t_{calc.}$2,26<$t_{tab.}$6,37); $CA_{1M1/40PVA}$ and $CA_{2M1/40PVA}$ – 19,14% ($t_{calc.}$2,10<$t_{tab.}$4,06); $CA_{1M1/40\Delta PVA}$ and $CA_{2M1/40\Delta PVA}$ – 46,63% ($t_{calc.}$2,10<$t_{tab.}$14,16); $CD_{1M1/40PVA}$ and $CD_{2M1/40PVA}$ – 19,88% ($t_{calc.}$2,09<$t_{tab.}$3,44); $CD_{1M1/40\Delta PVA}$ and $CD_{2M1/40\Delta PVA}$ – 16.77% ($t_{calc.}$2,20<$t_{tab.}$3,53).

Examining the influence of the type of board, used in the joints, on the stiffness coefficients and comparing the values of the results obtained in the joints by staples with wood of pine and OSB members and those of pine and PB members were established the higher values in joints with pine and OSB members with the exception of the end-to-face butt joints with reinforcing member ($CE_{2M1/40\Delta PVA}$ and $CA_{2M1/40\Delta PVA}$) where percentage difference was insignificant. The following percentage differences were established: $CE_{1M1/40PVA}$ and $CA_{1M1/40PVA}$ – 31,34% ($t_{calc.}2{,}20<t_{tab.}6{,}01$); $CE_{1M1/40\Delta PVA}$ and $CA_{1M1/40\Delta PVA}$ – 14,86% ($t_{calc.}2{,}20<t_{tab.}2{,}89$); $CE_{2M1/40PVA}$ and $CA_{2M1/40PVA}$ – 2,5% ($t_{calc.}2{,}11>t_{tab.}0{,}45$); $CE_{2M1/40\Delta PVA}$ and $CA_{2M1/40\Delta PVA}$ – 34,25% ($t_{calc.}2{,}13<t_{tab.}10{,}68$).

Determining the percentage differences between joints by means of staples of pine and OSB members and pine and PW members, as well as pine and PB members and pine and PW members, higher values of the stiffness coefficients were determined in joints of members of pine and PW, as follows: 17,11% ($t_{calc.}2{,}09<t_{tab.}2{,}82$) at $CE_{1M1/40PVA}$ and $CD_{1M1/40PVA}$; 23,02% ($t_{calc.}2{,}12<t_{tab.}3{,}21$) at $CE_{1M1/40\Delta PVA}$ and $CD_{1M1/40\Delta PVA}$; 41,08% ($t_{calc.}2{,}14<t_{tab.}8{,}55$) at $CE_{2M1/40PVA}$ and $CD_{2M1/40PVA}$; 53,25% ($t_{calc.}2{,}45<t_{tab.}9{,}54$) at $CE_{2M1/40\Delta PVA}$ and $CD_{2M1/40\Delta PV}$; 43,10% ($t_{calc.}2{,}14<t_{tab.}8{,}43$) at $CA_{1M1/40PVA}$ and $CD_{1M1/40PVA}$; 30,80% ($t_{calc.}2{,}23<t_{tab.}6{,}51$) at $CA_{1M1/40\Delta PVA}$ and $CD_{1M1/40\Delta PVA}$; 42,57% ($t_{calc.}2{,}14<t_{tab.}8{,}67$) at $CA_{2M1/40PVA}$ and $CD_{2M1/40PVA}$; 69,26% ($t_{calc.}2{,}36<t_{tab.}12{,}24$) at $CA_{2M1/40\Delta PVA}$ and $CD_{2M1/40\Delta PVA}$.

## CONCLUSIONS

As a conclusion of the deformation analysis made of end corner butt joints with staples of members of pine and boards, the following more important conclusions can be drawn:

1. The greatest stiffness was found in a butt joint with two staples with adhesive and reinforcing member of pine and PW members ($CD_{2M1/40\Delta PVA}$ – 3878,37 N.m.rad$^{-1}$).
2. The reinforcement of the joints with a wood member results in higher values of the stiffness coefficients for all series of joints by means of staples of pine members and boards with significant differences.
3. From the tested joints, higher stiffness coefficient values were established in case butt joints compared to those end-to-face butt joints, with the exception of joints with a reinforcing member of pine and PW members with established inverse dependence.
4. Better deformation behavior is determined in joints of pine and PW members compared to those of pine and OSB or pine and PB with significant differences.

   The influence of the type of board used, OSB or PB, on the stiffness coefficients in joints with staples of pine members and boards were established. The stiffness coefficients are higher from 14,86% to 34,25% in joints of pine and OSB members compared to pine and PB with exception of the stiffness coefficients joints of the end-to-face butt joints with reinforcing member ($CE_{2M1/40\Delta PVA}$ and $CA_{2M1/40\Delta PVA}$) where percentage differences were insignificant.

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