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Failure modes in halved and tabled tenoned timber scarf joint by tension test

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HIGHLIGHTS

- Halved and tabled tenoned timber scarf joint was analysed to find the failure modes.
- 42 specimens with different joint geometries were subjected to tensile stresses.
- Three different failure modes were observed: compression, shear, and crack initiation.
- Load that caused crack initiation was obtained for all values of the width and height.
- The influence of the length of the overlapping surface was also analysed.

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ABSTRACT

The structural behaviour of halved and tabled tenoned scarf joint subjected to tensile stresses was experimentally analysed to find the different failure modes. A total of 42 specimens of Scots pine wood (*Pinus sylvestris* L.) were made. Specimens were divided into 8 groups corresponding to different joint geometries. Three different failure modes were observed: compression parallel to the grain in the notch area, shear parallel to the grain in the heel surface, and by cracking starting in the reduced cross-section. The load that caused crack initiation was obtained, and the influence of the length of the overlapping surface was analysed.

1. Introduction

Joints are where forces are transmitted between the elements of a structure. Generally less emphasis is placed on their design and calculation, although they are important and complex causes of frequent structural damage. The accuracy of computer aided manufacturing systems has led to the resurgence of carpentry joints. These had become less important in comparison with other types of mechanical or glued joints, due to the need for highly qualified workmanship. Consequently, in recent years numerous research works focusing on carpentry joints have been published, especially on joints in pieces at an angle, such as the birdsmouth joint in rafter to tie beam joints [1–3], the mortise and tenon joint [4–6], and extensive studies of the round dovetail joint [7–10]. However, few scientific references appear to joints where the members are connected by their ends to achieve greater length, such as the halved and tabled scarf joint, the stop-splayed and tabled scarf joint or the double dovetail scarf joint. These members usually work under tension and are found less interesting due to their greater limitations for structural use. Some research works of this type of joints are detailed below.

Sangree and Schafer [11] analysed the scarf joints existing in the Morgan Bridge, built in 1898 in Belvidere, Vermont. Four scarf non-tenoned joints with two bolts in the middle of the joint were tested by tension. The study was completed with a linear elastic 3D finite elements model. All specimens failed by shearing and two limit states appeared: failure by shear stress parallel to the grain in the specimens with straight grain, and perpendicular to grain stress in the specimens with a deviation of grain greater than 7°. Failure perpendicular to grain tension stress was achieved with a lower strength than usual in this type of specimen. Sangree and

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Schafer [12] also analysed the behaviour of the stop-splayed and tabled scarf joint with transverse key. Mechanical tests on four specimens simulating real joints in Pine Grove Bridge were performed. The study was completed using a finite element simulation with the same characteristics as the one carried out on halved and tabled scarf joint. They studied joint strength, considering oblique and straight keys, as well as the influence of bolts. Kobayashi [13,14] analysed the behaviour of halved and tabled tenoned scarf joint without a key and subjected to bending. Using an analytical calculation method he obtained the strength and rotational stiffness of the joint in the plastic region, obtaining good fits with experimental values. Aira [15,16] numerically analysed the stress distribution of halved and tabled scarf joint, highlighting the influence of the size of the finite element mesh in stress distribution at the points where stress singularity occurs.

In this research work the behaviour of halved and tabled tenoned scarf joint subjected to tension test was analysed in order to determine failure modes and to compare theoretical strength values with the experimental results.

2. Materials and methods

42 specimens of Scots pine wood (*Pinus sylvestris* L.) with 48 × 148 mm in cross-section and 1932 mm in length were manufactured with a halved and tabled tenoned scarf joint half-way along their length, Fig. 1. The specimens were divided into 8 groups (A, B, C, D1, D2, D3, E1 and E2) corresponding to different joint geometries, Table 1.

The pieces were selected at the sawmill (Valsaín sawmill, Segovia, Spain) from the highest commercial visual grades (knots accepted only in one face and with a diameter not greater than 10 mm, slope of grain less than 1/10 and no wanes). The timber pieces were conditioned at 20 ± 2 °C temperature and 65 ± 5% relative humidity. They were then planed and divided into two parts by cutting the halved and tabled tenoned scarf joint. The structural grade according to Spanish visual grading standard UNE 56544 [17] is ME-1, which corresponds to strength class C27 according to EN 384 [18], EN 338 [19] and EN 1912 [20].

The tests were conducted according to the procedure described in the EN 408 [21] standard for tension testing. The free length between the testing machine clamps was nine times the largest cross-section dimension (9 × 148 = 1332 mm), Fig. 2. Load was applied by constant loading head movement, reaching maximum load within 300 ± 120 s, Table 1.

From a simple analysis of the mechanism of transmission of the axial force, *N*, from one piece to the other, three basic modes of theoretical failure corresponding to the three critical rupture surfaces can be established (Fig. 3):

(a) Compression parallel to the grain in the notch (front area, $b{\cdot}t$), producing a normal stress $\sigma_{c,0}$, that can be obtained according to Eq. (1), assuming a uniform distribution, Fig. 4a.

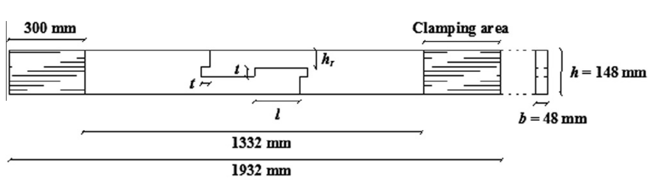

Fig. 1. General geometry of specimens.

Table 1
Dimensions of joint geometries.

Type	Number	t (mm)	h_r (mm)	l (mm)	l/t	Load head velocity (mm/min)
A	9	13	67.5	280	22	1.1
B	9	21	63.5	168	8	0.7
C	9	72	38	280	4	1.5
D_1	3	21	63.5	280	13	1.5
D_2	3	63	42.5	280	4	1.5
D_3	3	105	21.5	280	3	1.5
E_1	3	21	63.5	126	6	0.7
E_2	3	21	63.5	210	10	0.7

Fig. 2. Test device with different geometries.

$$\sigma_{c,0} = \frac{N}{b \cdot t} \tag{1}$$

(b) Shear stress in the heel surface (overlapping surface, $b{\cdot}l$), τ_v, obtained according to Eq. (2), assuming a uniform distribution, Fig. 4b.