FIRE RESISTANCE OF THE STRAW BALE WALLS

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UDK: 624.011.72:614.84
DOI:10.14415/konferencijaGFS2017.044

Summary: *Straw as construction material deserves considerable attention as a natural, energy and environmentally sustainable material in the modern period of building sustainable creation. Straw bales meet the requirements of sustainable architecture, but different researches have also shown satisfying specific significant level of certain mechanical characteristics. In this paper, fire resistance of load-bearing and non-loadbearing plastered and un-plastered walls made of baled straw, or wall panels with insulation of baled straw was considered. Fire resistance tests of the straw baled walls are relatively rare in the world and performed in accordance with different standards. Practically, almost all findings of such tests show a surprisingly encouraging results.*

Keywords: *Straw bales, Walls, Fire Resistance*

1. INTRODUCTION

A large number of recent studies on straw as natural material inline with sustainable architecture developments, shows that straw can meet the demands of modern sustainable architecture and contribute to the effect aimed to development of modern construction elements made of straw or straw bales. Development of new construction kits made of straw, or in combination with other materials, is focused to the elements that can adapt to market demands, where evaluation of the benefits and shortcomings to the specific requirements of the construction is integral part of the process.
In this regard, evaluation of fire resistance represents an important aspect of such construction. Wide public, but engineers and architects as well, do not know much about fire resistance of straw bales walls and kits made with straw bales, or even have specific prejudices towards behaviour of the straw bales and straw bales load-bearing and non-loadbearing walls in case of fire.

2. MODELLING OF FIRE ACTIONS

According to the research and analysis, it is widely accepted that majority of fires can be modelled through temperature - time curves. The standard that is internationally accepted in Europe, Australia, New Zealand and many other countries for standard fire action in fire resistance test is the ISO Standard 834-1 from 1991. The International Standard ISO

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834-1, Fire Resistance Tests - Elements of Building Construction defines the standard curve temperature-time for fire modelling in fire resistance tests conducted in firelab's test furnaces. Eurocode 1- EN 1991-1-2:2002 has also accepted this fire curve as a nominal fire curve. The Standard-temperature-time curve is given by:

$$T = 345 \log_{10} (8t+1) + 20 \quad (1)$$

where

T - gas temperature in test furnace [ºC],
t - time of fire testing [min].

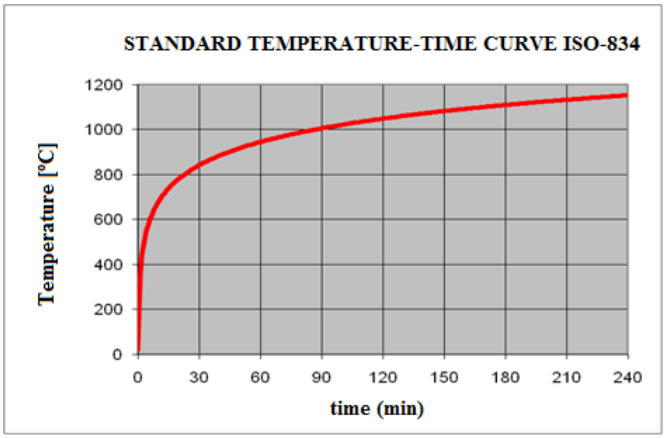

Figure 1. Standard Temperature-Time Curve ISO-834 [4]

Standard fire curve that is used in USA is Standard temperature-time fire curve as defined by ASTM 119 - Standard Test Methods for Fire Tests of Building Construction and Materials. It is defined by a number of discrete points according to *Table 1*.

Table 1. Discrete points of ASTM 119 Curve [15]

Time	Standard Fire Temperature
minutes	°C
5	538
10	704
30	843
60	927
120	1010
240	1093
480 and over	1260

In 1992, Lie [14] developed the following equation to represent the ASTM E119 time-temperature curve as:

$$T = 750 \left[1 - e^{-3{,}79553\sqrt{t_h}}\right] + 170{,}41\sqrt{t_h} + T_0 \quad (2)$$

where

T - gas temperature in furnace;
t_h - time of fire testing in hours;
T_0 - temperature before testing,

The *Figure 2* illustrates the given equation.

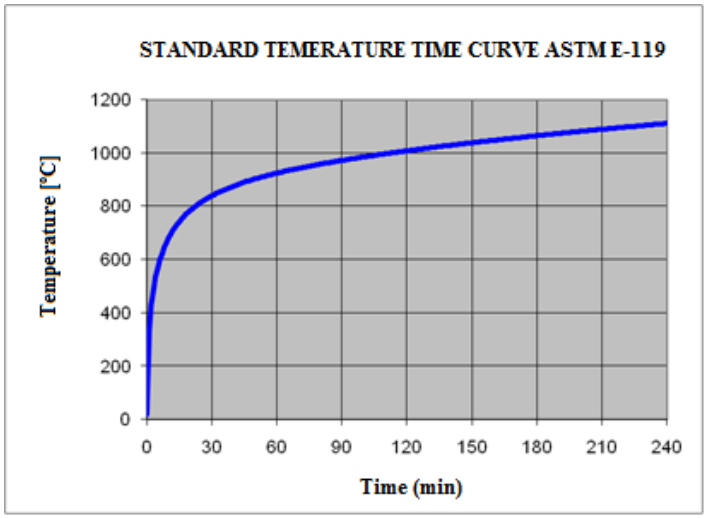

Figure 2. Standard Temperature-Time Curve ASTM E-119 [4]

The comparison of these two five curves is given at *Figure 3*. The diagram shows no major differences between these two standard time-temperature curves. Both these curves will be used in assessment of fire resistance of straw bale walls in this paper.

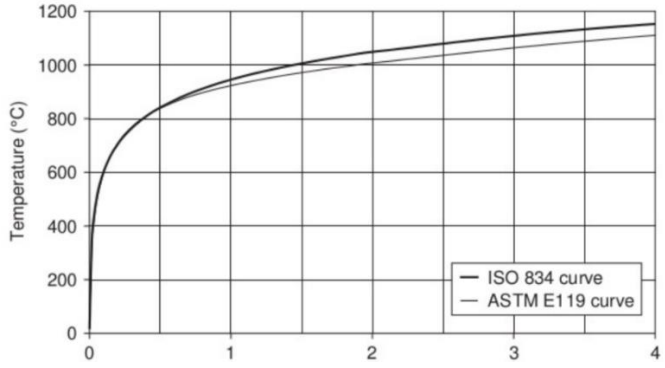

Figure 3. Comparison of Standard Temperature-Time Curves [8]

3. FIRE RESISTANCE RATINGS

The fire resistance of building components and constructions are classified in different fire resistance classes or combinations of those. The different fire resistance classes specify different performance criteria. Normally the fire resistance classification is followed by as a time limit in minutes 15, 30, 45, 60, 90, 120, 180, 240, or 360 which shows the time the performance criteria is fulfilled during a standardized fire test. The most considered requirements for the fire resistance classes are:

- R Load bearing capacity;
- E Integrity; and
- I Insulation.

The load bearing capacity, R, is the ability for a building element to resist a fire when exposed on one or several sides and when supporting an external load during a time period without losing its stability. The performance criteria varies on the type of construction. The two following things are distinguish between:

- ✓ Elements that are loaded in bending (for example floor structures and beams or compression in walls) where the requirements are the rate of deformation and maximum deformation;
- ✓ Elements that are axial loaded (for example columns and walls) where the requirements are the rate of deformation and maximum deformation.

The integrity E is the ability of a test specimen of a separating element of building construction, when exposed to fire on one side, to prevent the passage through it of flames and hot gases and to prevent the occurrence of flames on the unexposed side. The requirements are the following:

- ✓ cracks gaps of certain dimensions
- ✓ ignition of a cotton wool pad
- ✓ sustained flaming on the unexposed side.

The insulation I is the ability of a test specimen of a separating element of building construction when exposed to fire on one side, to restrict the temperature rise of the unexposed face to below specified levels.“Thus, when building element has designation, for example REI 120, that means this element fulfill the requirements for load bearing capacity, integrity and insulation for 120 minutes exposure to standard fire. Such ratings are for slabs and loadbearing walls. Designation EI 60 means that building element fulfill integrity and insulation requirements for 60 minutes exposure to standard fire conditions, like for non-loadbearing walls or doors. The only considered criteria for beams and columns is load bearing capacity R.” [4]

4. FIRE RESISTANCE TESTS OF STRAW BALE WALLS – EBnet, USA, (2006)

The Ecological Building Network (San Rafael, CA, USA) funded and oversaw the two fire resistance tests of straw bale walls in Intertek Testing Services NA Inc Fire Lab (Elmendorf, TX, USA) in 2006. The fire restsiance tests were conducted according to ASTM 119 - Standard Test Methods for Fire Tests of Building Construction and Materials. The first test was 1-hour fire resistance test of a non-loadbearing straw bale wall with

earth plaster, while the other was 2-hour fire resistance test of a non-loadbearing straw bale wall with cement stucco-plaster.

Figure 4. Preparation of the straw bale wall test specimen [9]

The test sample wall for 2-hour fire resistance test was 425 cm wide (14 ft) and 365 cm high (12 ft), made of straw bales 91.5 cm (36 in) long, 46 cm (18 in) wide and 35.5 cm (14 in) high and 19.2 kg (42.3 lbs) of weight. The each straw bale was tightened by two polypropylene ties. Each side of the wall was covered by galvanized self-furred stucco reinforcing mesh. The cement/stucco plaster was applied in two coats, 13 mm (1/2 in) thick each. The wall was allowed to sit for 36 days prior to testing.
During the testing, where temperature-time curve ASTM 119 was followed for two hours, the wall withstood the standard fire without passage of flame or gases hot enough to ignite cotton pad (integrity).

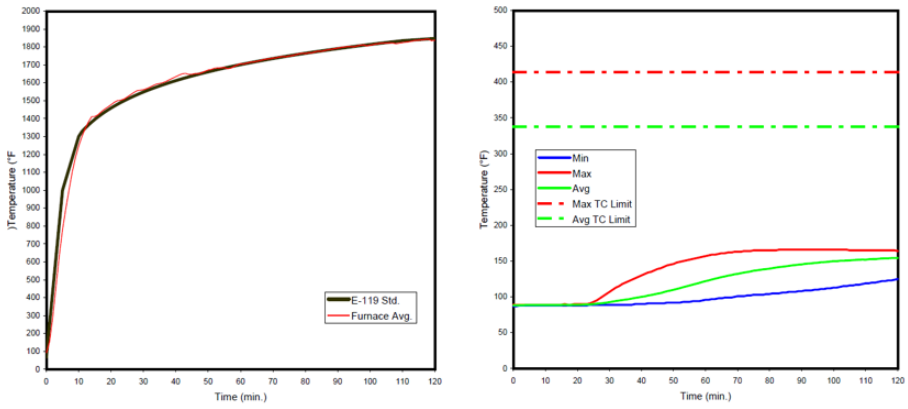

Figure 5. Furnace interior temperatures (left diagram) and minimal, average and maximal cold side temperatures(right diagram) [9]

The Test Report also states that transition of heat through the wall during the test did not raise the average temperature on the unexposed surface more than 121 ºC (250ºF), nor any individual temperature more than 163 ºC (325 ºF) (Insulation). The Test Report declared this specimen to have fire resistance of 120 minutes.

Figure 6. End of test [9]

The second test was performed for 1-hour fire resistance test of a non-loadbearing straw bale wall with earth plaster. The dimensions of the wall were the same. The wall was made of same straw bales. The wall constructed in a loadbearing test frame and hydraulic pump was used to introduce superimposed load of 8.75 kN7m' (600 lbs/lineal foot). The earthen plaster was applied in two coats, 13 mm (1/2 in) thick each. The wall was allowed to sit for 28 days prior to testing.

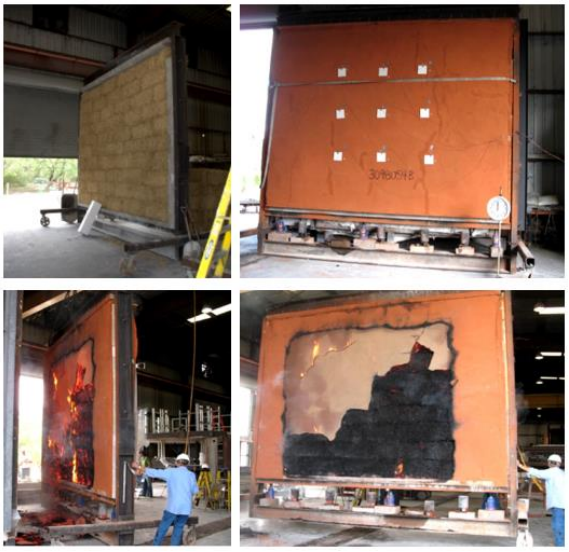

Figure 7. Photos before and after testing the specimen [10]

During the testing, where temperature-time curve ASTM 119 was followed for one hour, the wall withstood the standard fire without passage of flame or gases hot enough to ignite cotton pad and that transission of heat through the wall during the test did not raise the average temperature on the unexposed surface more than 121 ºC (250ºF), nor any individual temperature more than 163 ºC (325 ºF). Thus, the specimen was declared to have fire resistance of 60 minutes.

5. FIRE RESISTANCE TESTS OF STRAW BALE WALLS – CTU, PRAGUE, CZECH REPUBLIC (2011)

Fire resistance tests of straw bale load bearing walls were conducted in Czech Republic in 2011. The testing was performed in an authorized laboratory "PAVUS". The tests were done based according to ČSN EN 1363-1: 2000 Fire Resistance Tests: Part 1: Basic Requirements and ČSN EN 1365-1: 2000 Fire Resistance Tests for load bearing elements; Part 1: Walls.

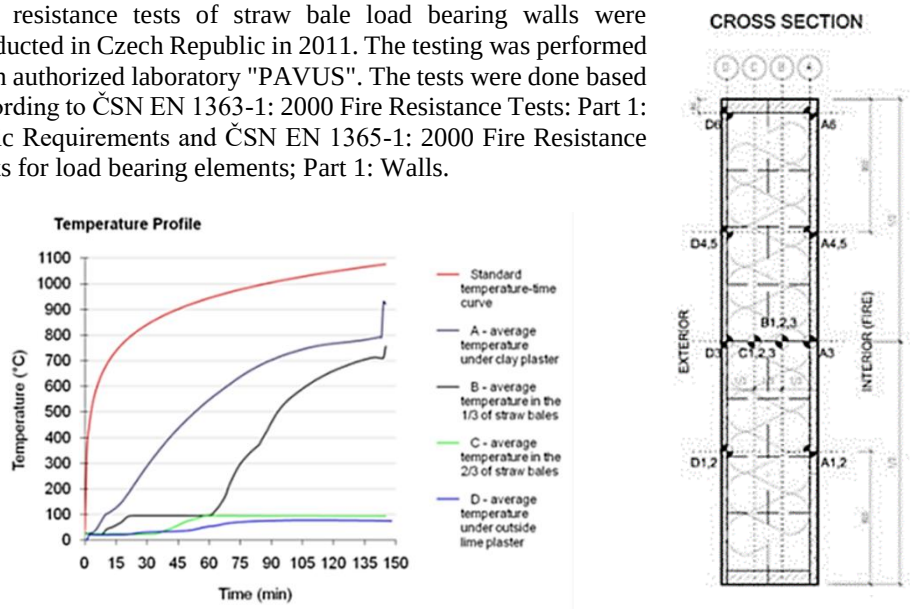

Figure 8. Temperatures in the wall during the test and cross section of the wall [16]

Tests were done using Standard Temperature-time curve ISO-834. One test showed that the load-bearing wall made of straw bales, plastered on both sides, loaded with 12 kN/m' resisted to standard fire for 2 h 26 min.

Figure 8. Photos from testing – CTU, Prague [16]

According to EN 1365-1: 2000 Fire Resistance Tests for load bearing elements; Part 1: Walls, the specimen was awarded the ranking of fire resistance REI 120, in terms of the load-bearing capacity, integrity and insulation criteria for a standard fire of 120 minutes. Wall panels framed with wooden studs and filled by baled straw, loaded with 20 kN/m' withstood a standard fire for a period of 1 hour and 6 minutes, and were awarded the ranking of fire resistance REI 60.

6. OTHER FIRE RESISTANCE TESTS OF STRAW BALE WALLS

Two small scale ASTM E-119 fire tests were conducted in 1993 at the SHB Agra lab in Sandia, New Mexico, USA. The plastered faces straw bales wall was resisting the transmission of flame and heat for two hours. The other un-plastered straw bales wall withstood the heat and flames of the furnace for 30 minutes before flames penetrated a joint between bales. A full scale ASTM E-119 fire test at the University of California Richmond in Field Station in 1996 easily passed the criteria to qualify as a one hour wall. The Appropriate Technology Group at Vienna Technical Institute conducted an F90 test in 2001, which gave a plastered straw bale wall a 90 minute fire resistance rating.
The Danish Fire Technical Institute tested a plastered straw bale wall with exposed studs on the fire side as a worst-case scenario in 2001, and after 30 minutes of test, the temperature on exposed side was 1000 °C, while the temperature on unexposed side rose just 1 °C. It is not clear which heating regime was applied during the test.

7. CONCLUSION

Fire resistance tests of straw bale walls or construction kits with straw bale conducted so far show encouraging results in addition to its environmental credentials, and its excellent insulation value. Since there is no fire without either origin of heat, fuel and oxygen, compressing the straw into a dense block dramatically decreases the ability of oxygen to feed a fire at the straw. This is probably the reason for such fire resistance documented in fire resistance tests. However, knowledge on fire resistance of elements made of straw bales is still incomplete and require more fire resistance testing, that will take in consideration type of straw, its chemical composition, density of straw bales, composition and design of different kits made of straw bales including the other factors and even large scale tests not conducted on building elements only, but performed on whole structures as well to asses effects of other building elements to fire resistance of straw bale walls.

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ОТПОРНОСТ НА ПОЖАР ЗИДОВА ОД БАЛИРАНЕ СЛАМЕ

Резиме: *Слама као грађевински материјал заслужује пажњу као природни, енергетски и еколошки одржив материјал у савременом замаху периода одрживе*

градње. Бале сламе у потпуности испуњавају захтјеве одрживе архитектуре, али различита истраживања су такође показала да задовољавању и одређени значајан ниво механичких карактеристика. У овом раду, разматрана је отпорност на пожар носивих и неносивих малтерисаних и немалтерисаних зидова од балиране сламе, али и зидних панела са испуном од балиране сламе. Испитивања отпорности на пожар зидова од балиране сламе су релативно ријетка у свијету и изводе се у складу са различитим стандардима. Практично сва проведена испитивања показују изненађујуће охрабрујуће резултате по питању отпорности на пожар оваквих зидова.

Кључне ријечи: *балирана слама, зидови, отпорност на пожар*