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Experimental characterization of firebrand ignition of some wood building materials

Paper presents investigation on behaviour of wood construction material samples (plywood, oriented strand board, chipboard) in laboratory conditions as a result of a heat flux effect from naturally occurring flaming and glowing firebrands. The data of comparing ignition delay time of pine wood and wood-based construction materials (plywood, oriented strand board, chipboard) depending on the size and quantity of firebrands, initial temperature of samples, as well as the presence of air flow in firebrands falling zone is obtained. Ignition probability and conditions of wood construction materials as a result of the thermal effect of flaming and glowing pine firebrands are also studied. The obtained data allowed one to judge that according to chosen experimental parameters, the ignition time decreased with increasing air flow, as well as with an increase in the size and number of particles. It was experimentally confirmed that particle size plays a significant role in igniting of building structure. If the characteristic particle size is less than a certain characteristic value, which can be defined as the ratio of its volume to the surface area in contact with wood, then ignition mode with an abrupt maximum of temperature near phase boundary is not appear.

Keywords: firebrands, fire exposure, wood construction materials, ignition.

Introduction

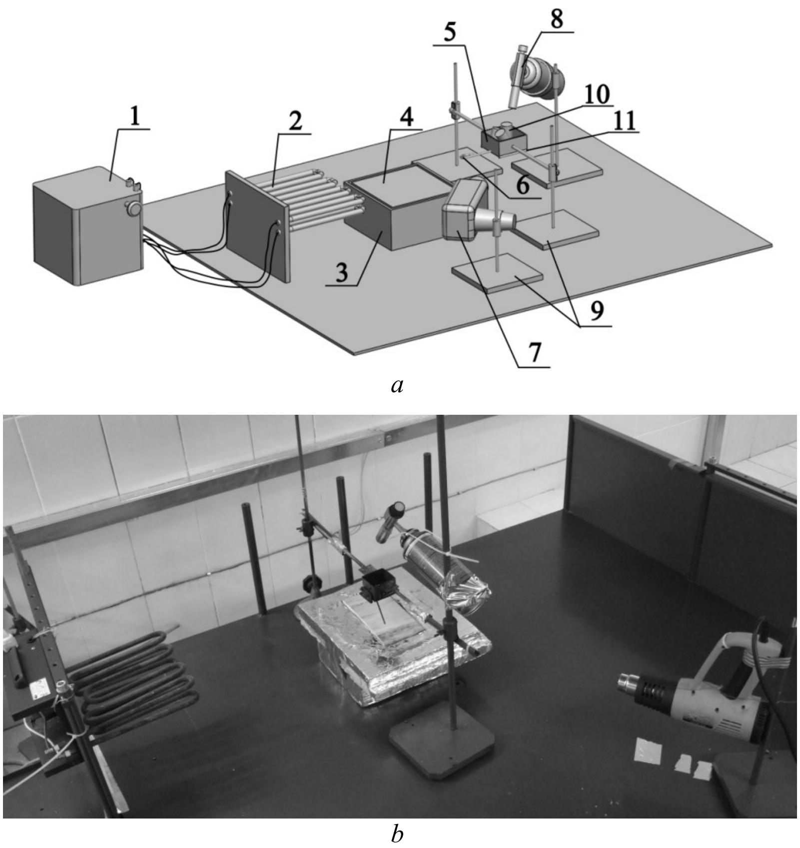
Wildfires are one of the most serious problems of the world. The scale of the damage caused by wildfires around the world is catastrophic [1]. It can be the cause of wooden bridges, oil product depots, buildings in cities ignition. Flaming and glowing firebrands, which are formed due to the burning of forest combustible materials, cause particular interest. These firebrands can be carried away over long distances by falling into a convective column that forms above the fire zone and lead to a new fire. Moreover, in flight they burn in flameless conditions [2]. Thus, one of the damaging factors of wildfires is the burning elements of forest combustible material, which can be also carried away to a territory of urban environment [3]. This problem is actively researched in Australia, USA, Canada, Portugal, and Greece.

Large-scale wildland and wildland-urban interface (WUI) fires have happened more frequently in recent years. Direct flame contact, radiant heat, and burning firebrands (or embers) have been identified as three principal ways that cause fire spread in the wildland and WUI [4–7]. However, only burning firebrands can initiate a new spot fire at distances further than 60-m away from the main fire front [8]. Spotting due to firebrands also referred as the firebrand phenomenon can overpower fire suppression efforts and becomes the dominant fire spread mechanism [9]. The spotting process includes three phases: firebrand generation, transportation, and ignition of the recipient fuel.

The ability of a firebrand to travel far way and start a new fire is a function of its physical properties and the environmental parameters [10]. Primary physical properties of a firebrand include mass, size (aerodynamic) shape, surface temperature, heat flux, and the heat of combustion of the fuel. The shape and dimensions are critical factors in firebrand transport. The mass and heat of combustion determine the total available heat energy from the firebrand. Surface temperature and heat flux play an important role in heat transfer from the firebrand to the recipient fuel. Environmental conditions influence all three phases of the firebrand phenomena. Key parameters include relative humidity, environmental temperature, wind speed, terrain conditions, and the condition of the recipient fuel. Among the environmental parameters, wind speed is critical effecting breakage of burning fuel leading to the generation of firebrands, transport mechanism (e.g., travel distance) and the burning behavior. Softwood is usually used in construction as a load-bearing structure, and hardwood is used as a finishing material. One of the factors determining fire hazard of wood [11] is its capacity to ignite and to stimulate fire propagation. Aim of this work is to study behaviour of wood building material samples in laboratory conditions as a result of heat exposure from a point source.

Experimental

The following laboratory setup was used to study the ignition probability of wood construction materials from flaming and glowing firebrands (Fig. 1).



1 — laboratory autotransformer; *2* — heating element; *3* — pallet; *4* — wood sample; *5* — cell; *6* — stopper; *7* — heat gun; *8* — burner; *9* — tripods; *10* — particle samples; *11* — bracket

Figure 1. Scheme (*a*) and photo (*b*) of the experimental setup

Experimental equipment involves the following devices: a scientific infrared camera JADE J530SB equipped with an optical filter whose operating wavelength is 3.1–3.3 μm which allows one to record the temperature in the range of 300–800 ºC; a video camera Canon HF R88 applied for estimating the ignition delay for considered samples made of wood construction materials; a moisture content analyzer AND MX-50 for controlling moisture content of the studied samples; AND HL 100 scales to control the initial particle mass and the mass of wood sample.

The wood sample was preheated with a heating element to a temperature of 200–220 ºC for 4 minutes [12]. Thus, the conditions were simulated when a wooden structure is exposed to heat flux from an approaching front of wildfire [13, 14]. Concurrently, particles were placed in the cell 5 mounted on the tripods 9, which had openings in the base sufficient for uniform heating of the particles, but excluding the possibility of particles falling out during the experiments. The volume of cell allowed one to place single particles in it, as well as groups of particles. Particles fell onto the wood sample when the sliding bottom of the cell was opened. Bottom parts were attached to the cell walls with hinges and were fixed in a horizontal position by a stopper 6. Two halves of the bottom fell under their own weight and firebrand fell when the latch was pulled out.

Particles were ignited and carried to a smoldering state with two gas burners 8. One burner was placed under the cell 5, and the other above it (Fig. 2) for uniform heating. After reaching the required temperature on the surface of sample, the substrate with sample was moved under the cuvette with particles preheated using gas burners, and they were discharged.

Plywood, chipboard and oriented strand board (OSB) are used as the samples of wood construction materials which are popular in the market.

The main parameters of samples are presented in Table 1.

Table 1

Sample parameters of construction materials

	Plywood	OSB	Chipboard
Size, [mm]	150×150	150×150	150×150
Thickness [mm]	21	18	18
Density, [kg / m^3]	650÷690	570÷590	570÷590

The samples were isolated from the environment with a heat-insulating material so that one of the surfaces remained exposed to heat from falling particles. A photo of the sample before the experiment is shown in Figure 3.

Figure 2. Photo of the flame effect on particles

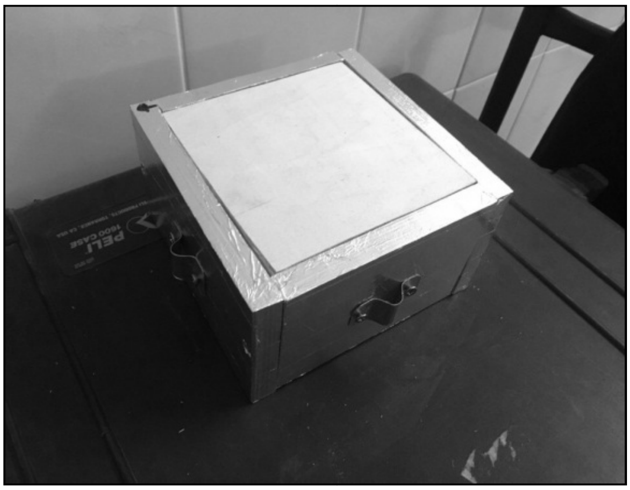


Figure 3. Photo of the sample before the experiment

The temperature during heating on the wood surface was controlled using an infrared camera. Figure 4 shows the thermogram of a wood sample as a result of heating by tubular heating element and the minimum (441 K), maximum (505 K), and average (479 K) temperatures on the surface of sample (in selected area 1 in the thermogram) obtained using Altair software. Previously in [17], it was found that firebrands of bark and branches were formed more often in a large wildfire. In current experiment, we used rectangular laths as particles that coincide in size with the typical particle sizes determined during field experiments [15]. Photos of the samples are shown in Figure 5.

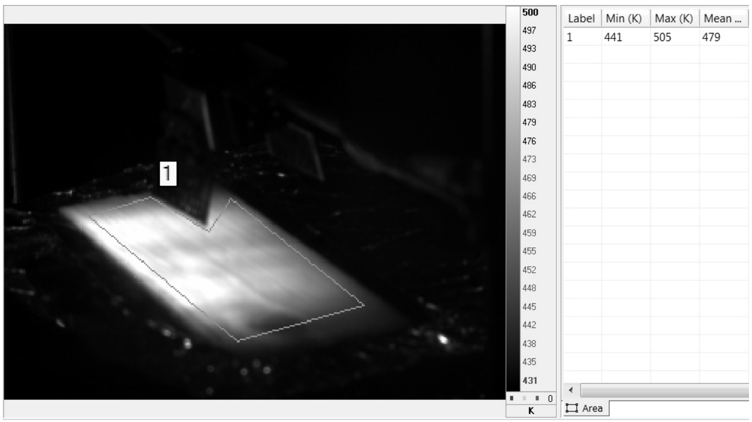


Figure 4. Thermogram of a wood sample after heating

Figure 5. Model particles

The particle length in this experiment was: (20±2; 40±2; 60±2) mm. The moisture content of particles did not exceed 10 %, for samples of wood construction materials it was 6–8 %.

Glowing firebrands, which effects the surface of sample, are of particular interest in current research. The case when glowing firebrands that form during a wildfire can accumulate on the roof and in corners of buildings, fences, or find a way to get inside premises and ignite it is simulated in these experiments.

The optimal particle ignition time was preliminarily selected (Table 2), at which the particle smoldering phase was achieved [18–19]. Particle burner time depended on particle size and quantity. Particle temperature was monitored using a JADE J530SB infrared camera.

Under natural conditions, the effect of firebrands on various wooden structures is accompanied by a number of natural factors, in particular, the action of a heated air stream from the front of a wildfire. Glowing firebrands discharged in the experiments onto wood samples were blown using a heat gun, Interskol FE2000-E brand, with a stream of heated air at a speed of 1.5 m/s, 2 m/s and 2.5 m/s with corresponding temperatures of 40 ºC, 60 ºC, and 110 ºC. An air flow was directed to the surface of the wood sample into the particle discharge region using a nozzle. The ignition moment was recorded using a Canon LEGRIA HF R86 video camera.

T a b l e 2

Exposure time depended on particle size

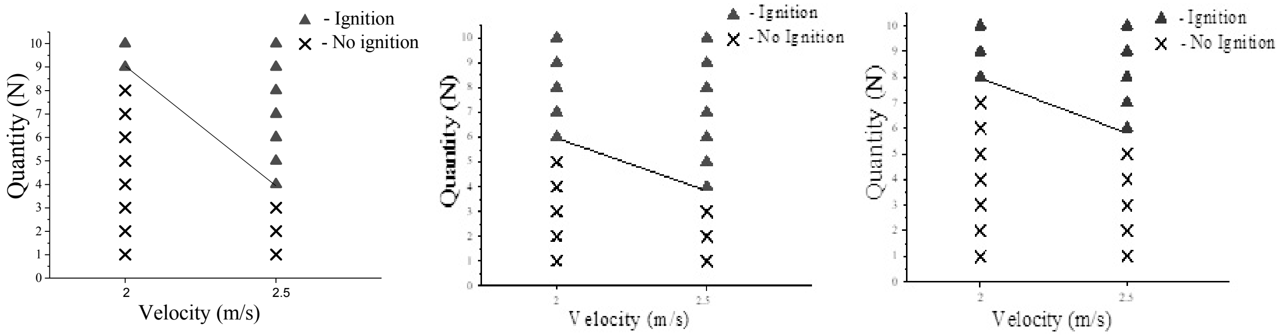
	Length, [mm]	Exposure time, [s]
Rectangular slats	20	15
	40	20
	60	25

A series of experiments began with one glowing firebrand, then two and so on up to 10 particles, thereby simulating the ignition of wood from one particle, as well as in the case of «fire rain». Three repetitions were performed for each experiment. If ignition occurred in at least one of the three cases, it was believed that the wood sample ignited. Ignition was understood as the appearance of a flame on the surface of samples of wood construction materials with subsequent steady burning.

Results and discussion

It was found that ignition of the samples was not observed in the range of wind speeds of 0÷1 m/s.

The probability of ignition of a preheated surface of plywood, chipboard, and OSB samples depending on the size of flaming and glowing firebrands and their amount interacting with this surface at various wind speeds was estimated as a result of a series of experiments (Fig. 6).



(a) *(b)* *(c)*

Figure 6. The dependence of wood samples ignition of construction materials on the size and quantity of glowing firebrands at air flow rates of 2 m/s and 2.5 m/s, where *a* is plywood, *b* is oriented strand board, *c* is chipboard

Analysis of the graphs shows that with increasing wind speed; the probability of wood ignition by particles of the same size increases. In particular, with an increase of wind speed from 2 to 2.5 m/s, the minimum number of particles with a length L = 40 mm, sufficient to ignite the wood, decreases from 7 to 3 particles. The number of particles also affects the ignition process of wood.

Figure 7 shows a typical group of images on particle ignition of a chipboard sample, on the surface of which glowing firebrands of length 40 mm in the amount of 6 pieces were discharged. The air flow rate was 2 m/s. It should be noted that the transition of particles from the glowing phase to the flame occurs due to the influx of the oxidizing agent from the heat gun. In particular, the transition occurred already at the 8th second in this case (Fig. 7), which subsequently led to the burning of chipboard over the surface.

8 sec.

40 sec.

1 min.

1 min. 30 sec.

1 min. 50 sec.

2 min. 10 sec.

Figure 7. A group of images on the effect of particles on a chipboard sample

Previously in [18–19], the experiment was conducted on the ignition of wood samples from a pine construction board as a result of exposure to flaming and glowing firebrands of pine bark. The experimental technique is similar. It was concluded that the probability of ignition of wood samples increases with increasing particle size, as well as with increase in air flow rate. The size of rectangular slats (40 mm long) was chosen based on this, which is close in size to particles of pine bark, which has the highest incendiary potential for the chosen experimental parameters (30×30 mm and 5 mm thick).

Figure 8 shows graphs comparing the ignition delay times of pine wood and construction materials (plywood, OSB, and chipboard) depending on the number of particles at air flow rates of 1.5 m/s, 2 m/s and 2.5 m/s.

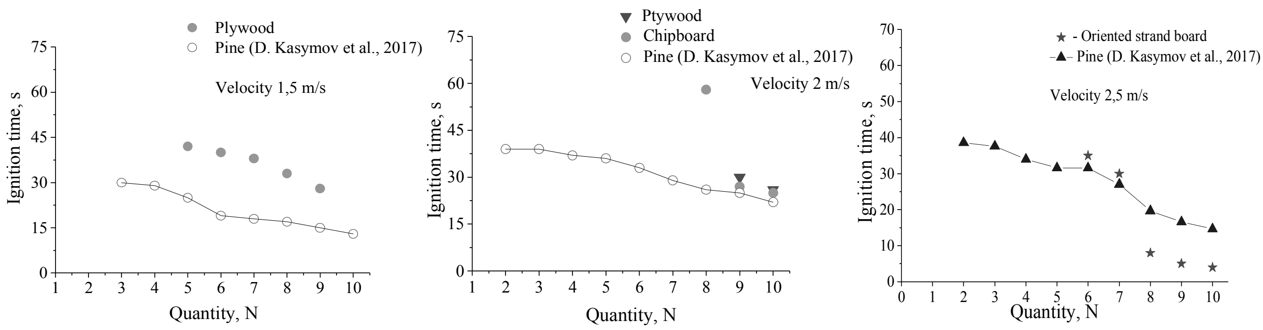


Figure 8. The ignition delay times of pine wood and construction materials

There is a tendency to decrease the ignition time of samples with an increase in the number of particles according to the analysis of graphs (Fig. 8). It can be seen that in the cases with plywood and chipboard samples, the ignition times are close to the times of pine wood ignition in the case of bark particles, and in the case with OSB, a large number of particles (8–10 particles) are observed, the ignition time is significantly reduced, more than 2 times compared to a similar experiment with pine. The obtained data allows one to judge that, at the chosen experimental parameters, the ignition time decreased with increasing air flow, as well as with an increase in the number of particles.

Conclusion

The behavior of samples of wood construction (plywood, OSB, chipboard) was studied as a result of heat exposure from flaming and glowing firebrands.

It was found that ignition of the samples was not observed in the range of wind speeds of 0÷1 m/s. The considered construction materials from wood (plywood, OSB, chipboard) were more resistant to ignition with the chosen experimental parameters. Apparently, this is due to the composition of studied samples, which contains additional binding components (synthetic resins). In addition, the presented construction materials have a lower surface roughness, unlike a standard building board.

The use of IR diagnostics made it possible to estimate the temperature on the samples surface and to select the optimal heating time. Moreover, this made possible to control the phase of glowing firebrands before discharge.

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В.А. Тараканова, Д.П. Касымов, О.В. Гальцева, Н.В. Чичерина

Кейбір ағаш құрылыс материалдарының тұтануының экспериментттік сипаттамасы

Мақалада зертханалық шарттарда табиғи жағдайларда жану және бықсу бөлшектерінің жылулық әсерінің салдарынан ағаш құрылыс материалдары үлгілерінің (фанера, жоспарлы түрде алынған жоңқа тақтасы, сүрек-жоңқа тақтасы) беталысы бойынша зерттеу жүргізілген. Жанып жатқан бөлшектердің мөлшері мен санына, үлгілердің бастапқы температурасына, сондай-ақ бөлшектердің құлау аймағында ауа ағынының болуына байланысты қарағай мен ағаш құрылыс материалдарының (фанера, жоспарлы түрде алынған жоңқа тақтасы, сүрек-жоңқа тақтасы) тұтану уақытын салыстыру деректері алынды. Сондай-ақ, өртену жағдайлары және қарағайдың жанған, бықсыған бөлшектерінің жылу әсерінен ағаштан жасалған құрылыс материалдарының тұтану ықтималдығы зерттелді. Алынған мәліметтер эксперименттің таңдалған параметрлерінде ауа ағынының жоғарылауымен, сондай-ақ бөлшектердің мөлшері мен санының артуымен тұтану уақыты төмендегенін бағалауға мүмкіндік береді. Бөлшектердің мөлшері құрылыс құрылымын тұтандыруда маңызды рөл атқаратындығы эксперименталды түрде расталды. Егер оның көлемінің ағашпен жанасатын бетінің ауданына қатынасы ретінде анықтауға болатын бөлшектің тән мөлшері белгілі бір мәннен аз болса, онда фазалық шекараның жанындағы температураның күрт максимумымен тұтану режимі орындалмайды. Мұны жылу фенінен келетін және химиялық реакциялар нәтижесінде пайда болатын жылу мөлшерімен салыстырғанда жылудың сыртқы ортаға таралуы арқылы түсіндіруге болады. Бөлшектердің тән мөлшері мәселенің нақты тұжырымына және материалдың түріне, оның жылу өткізгіштік коэффициентіне байланысты болады.

Кілт сөздер: жанып жатқан бөлшектер, жылу әсері, ағаш құрылыс материалдары, тұтану.

В.А. Тараканова, Д.П. Касымов, О.В. Гальцева, Н.В. Чичерина

Экспериментальная характеристика воспламенения некоторых древесных строительных материалов

В статье проведено исследование в лабораторных условиях по поведению образцов древесных строительных материалов (фанера, ориентированно-стружечная плита, древесно-стружечная плита) в результате теплового воздействия от горящих и тлеющих частиц природного происхождения. Были получены данные сравнения времени задержки зажигания древесины сосны и древесных строительных материалов (фанера, ориентированно-стружечная плита, древесно-стружечная плита) в зависимости от размера и количества горящих частиц, начальной температуры образцов, а также от наличия воздушного потока в зоне падения частиц. Также исследованы условия зажигания и вероятность воспламенения строительных материалов из древесины в результате теплового воздействия горящих и тлеющих частиц сосны. Полученные данные позволяют судить о том, что при выбранных параметрах эксперимента время зажигания снижалось с увеличением воздушного потока, а также с увеличением размера и количества частиц. Экспериментально подтверждено, что существенную роль в воспламенении строительной конструкции играет размер частиц. Если характерный размер частицы, который можно определить как отношение ее объема к площади поверхности, соприкасающейся с древесиной, меньше некоторой характерной величины, то режим зажигания с резким максимумом температуры возле границы раздела фаз не реализуется. Это можно объяснить превалирующим отводом тепла во внешнюю среду по сравнению с количеством тепла, поступающим от теплового фена и возникающим в результате химических реакций. Характерный размер частиц будет зависеть от конкретной постановки задачи и типа материала, его коэффициента теплопроводности.

Ключевые слова: горящие частицы, тепловое воздействие, древесные строительные материалы, воспламенение.

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