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Causes of the Fire at an Indoor Shooting Range in Busan

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Abstract : On-site examinations and fire simulation were carried out to speculate on causes of the fire at an indoor shooting range in Busan. An experiment on the ignitability of unburned gunpowder was also conducted. Cigarette was the most likely source of ignition for the fire, while impact of a stray bullet failed to ignite the unburned gunpowder. The explosion in the shooting area was presumed to be caused by violent combustion of the polyurethane foam and unburned gunpowder accumulated on it. Fire safety measures include prohibit of use of profile polyurethane foam, complete clean-up of unburned gunpowder, and removal of steel components from the bullet trap.

Key words: indoor shooting range, fire simulation, source of ignition, cause of explosion

1. Introduction

A fire broke out at an indoor shooting range in Busan, on November 14, 2009, and killed 15 people, including 10 Japanese tourists. According to witnesses, there was an explosion before the fire engulfed the second floor of a five-story building. Fig. 1 is the plan view of the indoor shooting range. No casualties were found in the shooting area where there are 5 shooting lanes. It also shows the presumed location of fire start and two doors located between the rest and shooting areas. The size of the shooting area is about 7 m×17 m floor and 2.6 m high. The outer door was open whereas the inner door was initially closed, but later opened at 3 s after the onset of the fire. A plastic bag was in front of the shooting booth 1, and was presumed to be the location where the fire started. The National Institute of Scientific Investigation (NISI) concluded that the cause of the fire is impact of a stray bullet rebound from the bullet trap. In the past, however, impact of a stray bullet had never been reported as a cause of the fire at indoor shooting ranges to the authors' knowledge.

The restored footage of closed circuit televisions (CCTV) showed that the fire started in front of the shooting booth 1, and the inner door was opened by the pressure following the explosion in the shooting area. It took only 3 s that smoke from the shooting area filled up the rest area. It is necessary to review the potential sources of ignition and to speculate on the cause of the explosion.

The objective of this study is to review how the fire started and to presume the cause of the explosion, to

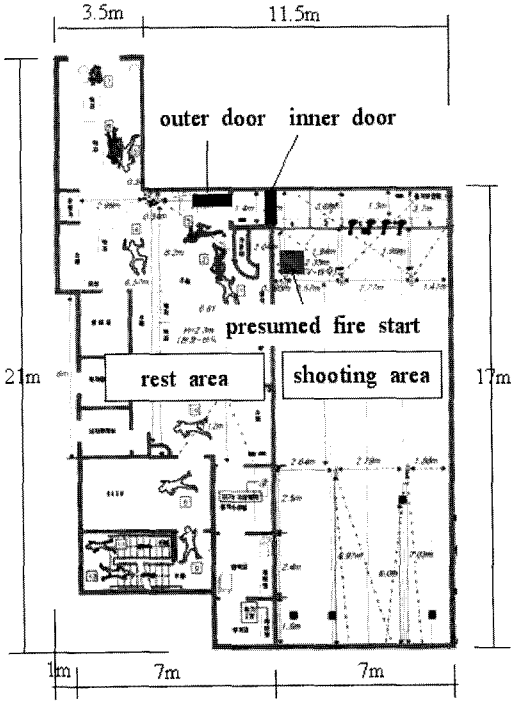

Fig. 1. Plan view of the shooting range.

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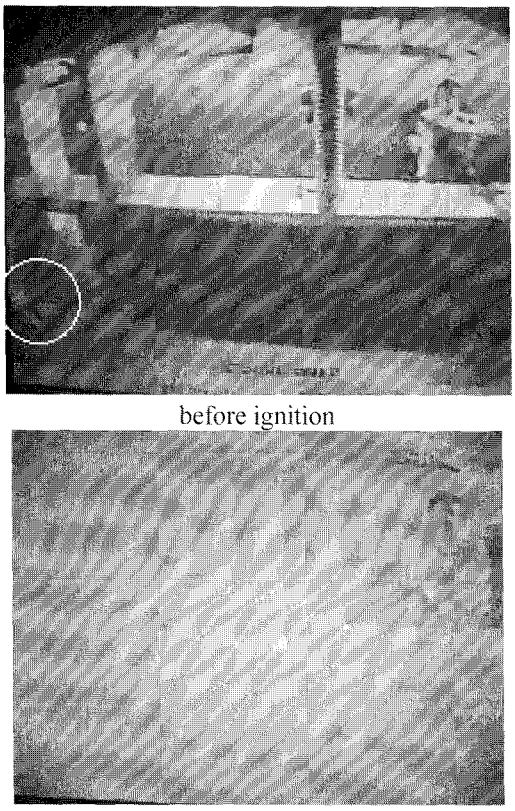


Fig. 2. CCTV footage around the fire start at shooting booth 1~3.

provide fire safety measures for indoor shooting ranges. The causes of the fires at indoor shooting ranges broken out in the past were investigated, and fire simulation was carried out by using a computational fluid dynamics model. On-site investigations and a direct shooting experiment on the unburned gunpowder were also performed.

2. Source of Ignition

Fig. 2 is the video clips at 1 s before and at the onset of the fire, taken from CCTV footage [1]. The fire was presumed to start at the plastic bag (inside the yellow circle in Fig. 2) near the shooting booth 1. Flame suddenly appeared in front of the shooting booths 1 and 2 when the tourist at the shooting booth 3 shot a bullet.

The potential causes of the fire, and the reported causes of the fires at indoor shooting ranges in the past were reviewed. Here are summary of the fires available in open literature.

A fire in 2006 at an indoor shooting range in Bangbae-dong, Seoul [2], was caused by the muzzle fire igniting the unburned gunpowder accumulated on the ground. 1died and 6 injured due to violent combustion of unburned gunpowder aspirated in the air by the fire extinguisher.

Total 25 fires at German indoor shooting ranges killed 20 people between 1967 and 1995 [3]. The causes for the fires were use of polyurethane sound absorber, unburned gunpowder, and spark at steel components in the bullet trap.

12 shooters were died in 1989, at an indoor shooting range in Jette, Belgium [4]. The fire was initiated when unburned gunpowder residues on the ground were ignited by muzzle spark. When one opened the door to bring a fire extinguisher, the gunpowder grains were aspirated and resulted in a violent, rapid combustion. The walls, covered with polyurethane foam in pyramid shape, where unburned gunpowder accumulated, were ignited violently like an explosion. The identified causes of the fire were ignorance of the fire danger of the acoustic insulation, use of highly toxic materials in the glue, ineffective disposal of unburned gunpowder, and incorrect ventilation.

In 2008, a flash fire broke out at the Virginia Beach indoor shooting range [5], and injured 7 people. Fire investigators concluded that gunpowder residue, stored just feet from the shooting booth, ignited the blaze. There were two more fires at the same shooting range, in 1991 and 1994, likely caused by the accumulation of lead dust, which was released when bullets hit targets. There were no injuries in those incidents.

The potential sources of ignition for the fire in Busan are as follows:

(1) impact of stray bullet

Fig. 3 is photograph of the bullet trap taken at on-site investigations, which is consisted of inclined steel plates and angles. The bullets are rebound when they hit the angle. NISI concluded that a stray bullet, which

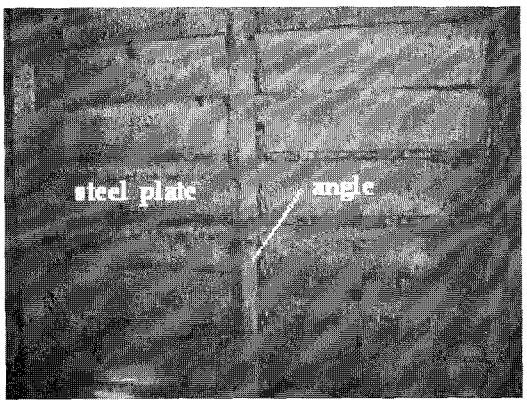
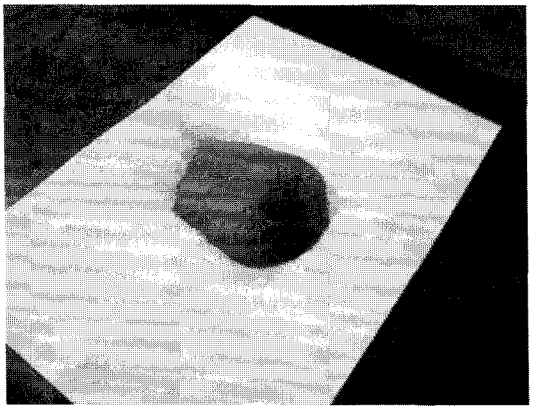
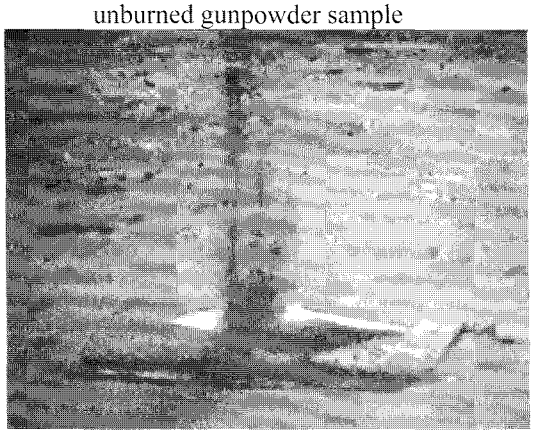


Fig. 3. Bullet trap.



unburned gunpowder sample



gunpowder scattering by hit of bullet

Fig. 4. Shooting experiment.

rebound from the bullet trap and drop to the plastic bag, ignited the unburned gunpowder in the plastic bag by its impact. Since the distance from the angle to the plastic bag is about 14 m, the bullet may lose considerable amount of its kinetic energy, and its impact is reduced dramatically by the bag itself and contents. In the plastic bag unburned gunpowder in a vacuum cleaner dust bag, burst balloons, fluorescent bulbs in paper carton, etc. Therefore, the stray bullets would not yield enough impact to the gunpowder. To confirm this, a direct shooting experiment was conducted at an indoor shooting range in Busan.

Fig. 4 represents the gunpowder sample used in the experiment and a snap shot at the moment of the bullet's hit. The gunpowder is 40 g, and at 5 m distance, 12 rounds of 9 mm beratta handgun were directly shot to the sample on the ground of the indoor shooting range. The bullets, without any absorption of impact by the plastic bag and without any loss of kinetic energy, failed to ignite the gunpowder. This result clearly shows that the impact of a spray bullet is not the source of ignition, and hence that the NISI's presumption on the source of ignition must be reexamined.

(2) spark at bullet trap

The source of ignition in the fires of Germany indoor shooting ranges [3] was mostly spark at steel components in bullet trap or bullet catcher. The bullet trap of the indoor shooting range in Busan shown in Fig. 3 is assembled by steel plates and angles, thus a bullet's hitting the steel components easily makes sparks. The CCTV footage showed, however, no evidence that s spark at the bullet trap traveled to the shooting booths. Spark at the bullet trap is, therefore, excluded from the possible sources of ignition.

(3) muzzle spark

Muzzle spark was the cause of indoor shooting range fires in Seoul [2] and Belgium [4]. In this fire, the distance from the shooting booth 3 to the plastic bag is more than 3 m, and it appears too far for the muzzle spark to reach the plastic bag. Although muzzle spark might ignite unburned gunpowder on the ground, the flame spreading from the shooting booth 3 toward the plastic bag was not observed in the CCTV footage.

(4) cigarette

Cigarette butts were found in the plastic bag, which is the presumed location of fire start. The source of most fires in the past was either spark at bullet trap or muzzle spark. In the present study, the CCTV footage eliminated both spark at bullet trap and muzzle spark from the possible sources of ignition. Since the plastic bag leaned against the wall in front of the shooting booth 1(see Fig. 2), smoke at the beginning of the fire might be unwatchable on CCTV footage. These make cigarette the most likely source of ignition for the fire.

(5) arson, explosive

No trace of an arson or explosion of an explosive in the shooting area was found in the CCTV footage or on-site investigations.

3. Cause of Explosion

The CCTV footage showed smoke filled up the entire rest area in 3 s from the inner door's open following an explosion in the shooting area. To investigate smoke movement, a fire simulation was carried out by using the NIST Fire Dynamics Simulator (FDS) v5 [6]. The grid size of 0.1 m×0.1 m×0.1 m, the fire size of 15 MW for 2 s at the beginning, the thickness of polyurethane foam of 5 cm were among the input data. All the walls and ceiling were covered with the polyurethane foam. The inner door was set to be open at 3 s from the onset of the fire ($t = 0$), according to the CCTV footage. No special treatments were made to simulate the explosion

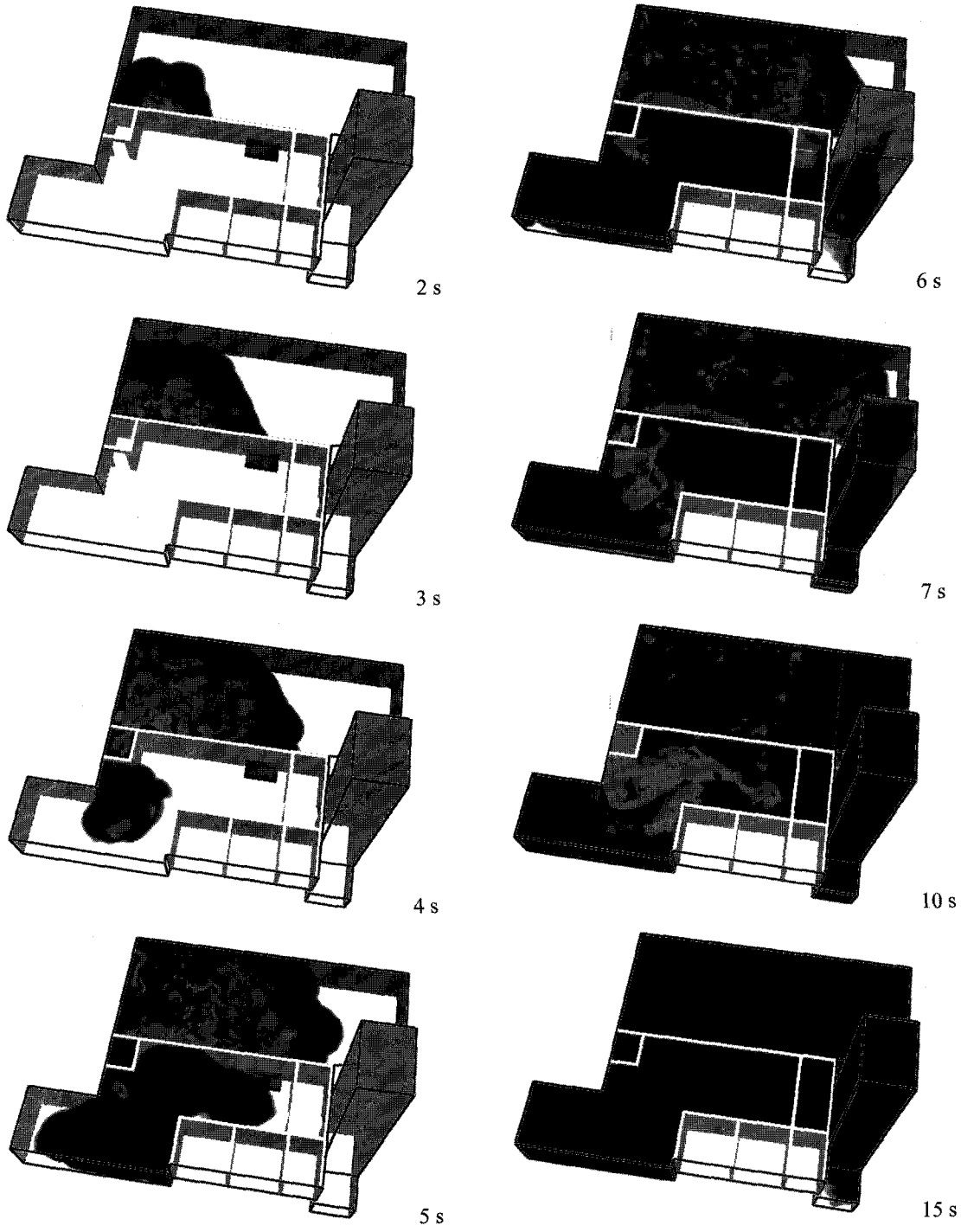


Fig. 5. Spread of flame and smoke.

in the shooting area.

Fig. 5 depicts spread of flame and smoke with time obtained from the fire simulation. Smoke produced by a rapid combustion of the polyurethane foam filled up the rest area at $t = 6$ s, and thus it took only 3 s from inner door's open. This result is consistent with the CCTV footage. This increased death toll in the rest area, and. It was also confirmed that the direction of fire spread and smoke movement seen in Fig. 5 is the same as shown at the scene.

In the Belgium fire [4], burning the polyurethane sound absorber on the walls was developed to a com-

bustion like an explosion. In the present study, there was an explosion at 3 s from the fire start(t = 3 s), and the resulting pressure was so high that the inner door might be opened despite of the presence of openings for ventilation on the ceiling. The explosion must be closely related with combustion of the sound absorber and unburned gunpowder. Since the polyurethane foam was of high porosity and egg crate shape, considerable amount of unburned gunpowder must have been built up there. This draws a presumption that the explosion in the shooting area was due to violent combustion of the polyurethane sound absorber and unburned gunpowder built-up on it. As the fire, started at the plastic bag, spread over the wall, the concentration of highly flammable and toxic gases could be rapidly increased by combustion of the soundproof material, and the unburned gunpowder grains were dispersed into the air. The explosion in the shooting area was therefore presumed to be caused by combustion of the sound absorber and unburned gunpowder.

4. Conclusions

On-site investigations and fire simulation by using a computational fluid dynamic model were conducted to speculate on the source of ignition and cause of the explosion for the fire at an indoor shooting range in Busan. The causes of the indoor shooting range fires broken out in the past were reviewed, and a shooting experiment was also carried out to confirm the ignitability of unburned gunpowder by impact of a stray bullet.

Cigarette is the most likely source of ignition among the potential causes. On the other hand, a stray bullet turned out to fail to ignite unburned gunpowder at the direct shooting experiment. The explosion in shooting area was presumed to be caused by the violent combustion of the polyurethane foam and unburned gunpowder residues. Prohibit of use of profile polyurethane foam as a soundproof material, complete clean-up of unburned gunpowder, and removal of steel components from the bullet trap are essential to prevent fires at indoor shooting ranges.

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