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Experimental investigation about fracture and resistance of PVC plastic comb binding due to the impact with the ground

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Abstract. Due to their low cost of manufacturing, light weight, and its flexibility, Polyvinyl chloride (PVC) are widely used in large equipment such as plastic comb binding. In order to design and improve resistance and durability of PVC base plastic comb binding, it is important to understand and predict the resistance, damage and fracture behavior of PVC comb binding during fall from height. We analyze the damage patterns and weight change in the plastic comb binding related to increasing fall height. Analysis of the distribution of forces and stresses based Experimental results can be used to find a solution to prevent the failure of the materials in similar circumstances.

Keywords: Polyvinyl chloride, plastic comb binding, impact, weight, energy distribution

1. INTRODUCTION

PVC is a major plastics material which finds widespread use in building, packaging, electrical/electronic and many other applications. PVC is a very durable which can be used in a variety of applications, rigid or flexible, white or black and a wide range of colours in between. Due to their low cost of manufacturing, light weight, high performance and flexibility, PVC are widely used as plastic comb binding. In order to design and improve plastic comb binding, it is important to predict the damage and fracture behavior of PVC under impact especially in impact of fall from height.

Some papers were analyzed and modelled the impact with the ground of some materials or objects. [1] discussed about the testing procedures for soils and pavements such as spectral analysis of surface waves method. In [1] method some sensors are used at some point on the surface of the ground to record vibration, energy and surface waves. [1] suggested a model to predict size, mass, and dropping height using the characteristics of the forces transmitted to the ground by the falling object or material. [2] modelled a simple primary secondary structure that damped impact and energy subjected to ground shock or impact and suggested a new method for the determination of the dynamic response of primary secondary systems. [3] is about the interaction of fluid and its container. They tested, water filled tanks during the impact with the ground. Using the experimental data, some numerical model has been

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developed for the analysis of the water sloshing in a tank during the impact with the ground. [4] Is a good survey for numerical approaches for the behavior of a composite panel during a water impact? The application of these approaches is in safety devices developed for airplane and helicopter falling in water. The loading that characterizes the impact with hard and soft surfaces is so different and therefore energy absorption systems designed for ground impact are not effective during a water impact. In this article we want to investigate about PVC impact with the ground. PVC is a solid material and the above models do not able to directly use for it.

About the modelling of direct impact between two object (none of them are ground) many research has been done. For example about bullet strikes to a steel, composite or any object. Our work has so different. First, when an object with plastic comb binding (PCB), fall from height, usually the height is low and related to low height the speed of collisions between PCB and ground is low. In the previous works in collisions, especially in ballistic impact or projectiles the speed is fast. The collision in low speed and its characteristics is completely different from high speed. Second difference between our work and others, is importance of physical parameters. In ballistic or projectile collisions or car crash, the main parameters are crack or crash of objects and the pattern of these cracks. In this work the main parameters are, weight and physical strength of PCB. In the meantime mostly in our tests the PCB under test is not broken, but in previous works all objects or materials are damaged, deformed or crashed. Similarities between our work and previous works are, importance and modelling of energy distribution in structure during the test and other related parameters to this distribution such as vibration of structure, surface waves. As molecular aspects, in our work and previous works, the arrangement of molecules and how they spread is important.

Based on the above descriptions, some previous works that focused on energy distribution during and after impact or collision is explained. [5] is a survey and review methods about penetration and perforation of plates by projectiles. These models covered a wide range of projectile-target configurations. These survey explained, the normal impact of monolithic metallic plates by non-deformable projectiles, non-normal impact by deformable projectiles, non-homogeneous metallic and non-metallic targets and pipes and tubes. Compute and plotting, transient plate profiles at various times after impact that is done at [5] is so important in our work. In [6] the numerical methods and simulation softwares for modelling dynamic events is evaluated. Impact between two objects and dynamic events during and after it, is so important in all collision or falling from height. Finally [6] is discussed about fault or incorrect predictions that do not correspond with reality. [7] is focused on an impact oscillator with a frictional slider. The main similarity between [7] and our work is impact and energy absorption and no damage to the structure under test. Based on the analysis of the structure motions [7] proposed an impact map with dynamical variables defined at the impact instants. The nonlinear dynamics of the impact system is analyzed using this impact map. [8] try to modelled effect of rock shapes on breakage. [8] is used smoothed particle hydrodynamics for modelling breakage and its growth on rocks. The smoothed particle hydrodynamics is a good model to explain the molecular motion during energy absorption, impact, pressure, tension or collision. In our work, PCB fall from height and we need an impact or falling model to analyze molecular motion in it. The smoothed particle hydrodynamics can be used for modelling molecular and particles motion.

In [9] typical concrete material models is evaluated in high dynamic response simulations. The main weakness in simulation softwares for modelling impact, tension, etc is material or object model and its energy distribution and absorption characteristics. In [9] a concrete structure is affected by severe shock and impact loads such as explosion. An accurate model combined with a simulation, should be able to predict the complex responses of concrete structure subjected to this scenario. In fact concrete is a mixture and maybe its molecular structure is similar to PCB, so concrete models can be used in a different manner to model PCB structure. [10] modelled the reducing the quality of ores since transportation from mine to destination. In [10] a mechanistic model is proposed to describe degradation caused by transfers and drops of separate particles of ores, based on crash mechanics and the distribution of total energies in original particles. This model is able to predict the cracks and the distribution resulting from any sequence of drops and has been validated with practical data. [11] evaluated the performance of the Optimal Transportation Meshfree method for seizing contact and fracture in terminal ballistics. Terminal ballistics is the study of how a projectile behaves when it hits to target and its kinetic energy release. The bullet's shape and impact velocity is important in energy distribution and release. Our experiments must be model kinetic energy distribution and release in an impact (falling from height) similar to [11], but the impact velocity in our experiments is so lower and we have no damage or crack during impact. In [12] impact damage of three-dimensional angle-interlock woven composite is studied. [12] extracted equations of the composite fiber under high strain rates to characterize the mechanical behaviors under impact. In [12] the composite fiber were assumed as transversely isotropic viscoelastic material. It is so interesting that we able to extract the equations of PCB to characterize mechanical behavior similar to [12]. PCB is elastic but unlike the [12] composite fiber is viscose or isotropic structure. In the meantime the velocity of impact and the amount of kinetic energy during impact is so different in our work, so our experiment is so complicate in comparison to [12]. [13] worked on UHPC[1] and shows improving the blast resistance of structural panels made from it. The term UHPC includes a broad range of materials such as defect-free, dense particle, engineered composite, multi-scale particle, and fiber-reinforced cementitious materials. In [13] the experimental results is used to build a multiscale model which accounts for structure and phenomena at two length scales. The models at the two length scales account for energy dissipation through granular flow of the matrix. [13] is significant for some reasons: first, the multiscale model has been verified by experimental results at two different length scales, second by incorporating information from multiple length scales, the multiscale model, simplify the design of UHPC materials to enhance resist blast loading. The main advantages of [13] are exact modelling of energy distribution in UHPC during pressure and crack that has a good adaptation with experimental data. Based on this accurate model, the broken area is predicted correctly at a specified pressure. [14] analyzed the form of damage patterns in a glass plate with polycarbonate backing. The main goal of [14] is showing the form of crash patterns in the glass plate related to impact velocity. They tested three projectile velocities, considering boundary conditions and improved modeling of brittle damage from impact on multi-layered system. The boundary conditions during impact to ground is so important in our experiments. In fact the damage, crash, any changing in form or physical characteristics of PCB is happened in the border of clash.

[1] Ultra-High-Performance Concrete

The paper is organized as follows: in Section2, the experimental tests are described with details; in Section3, the numerical results of experiments have been reported and finally conclusions are given in Section4.

2. MATERIAL AND METHOD

2.1. Experimental Investigations

The standard method to the study of an event consists of carry out appropriate tests. Therefore, a convenient experiment was performed in order to collect data, regarding the fall from height of a PCB and hitting the ground.

2.2. The PCB specimen

The specimen (Figure. 1) was built of a general PCB that used for binding books and lecture notes. For preventing fracture of combs, two PCBs are joined together by little pieces of stationary scotch. Figure 2 shows one of the final specimen. Because of the material importance in results, the PCB samples are carefully analyzed by bomem MB-series FT-IR spectrometer. The percentage of the ingredients of polyvinyl chloride based PCB are given in table 1. Because of little changes in the profiles during experiments, all samples are analyzed separately after each test.

To increase the accuracy and reduce the error, test is repeated 3 times with approximately similar material.

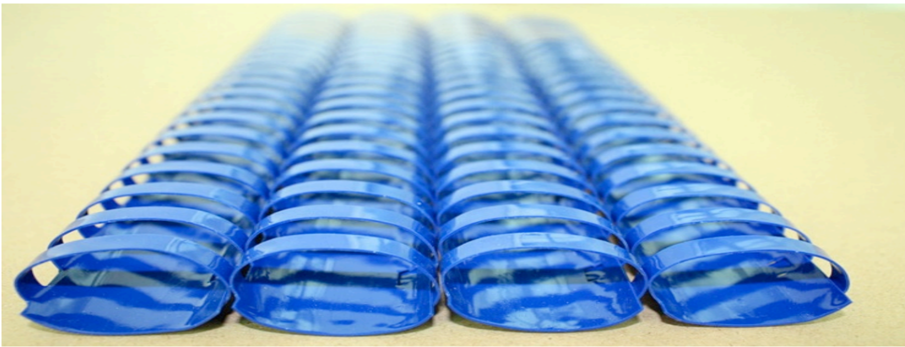


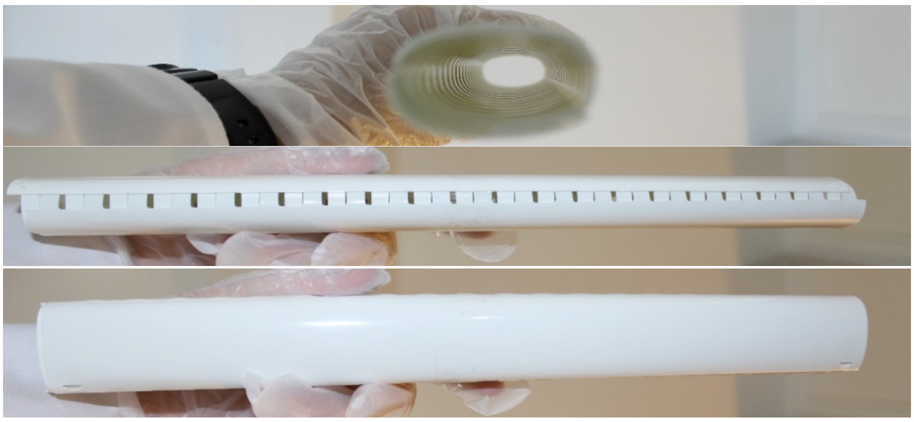
Figure 1. Typical samples of PCB used in experimental tests

Figure 2. Three different views of final specimen.

Table 1: The percentage of the ingredients of PCB elements.

	sample 1		sample 2		sample 3	
O	15.84	26.99	26.29	28.46	30.41	27.03
Mg	5.56	--	--	--	--	--
Cl	6.83	9.06	8.75	6.95	7.48	8.71
Ca	20.35	19.15	14.51	14.81	13.16	15.49
Ti	51.42	37.99	42.73	40.33	39.34	36.46
F	--	6.81	7.72	9.44	9.62	11.59
S	--	--	--	--	--	0.73

Each of our samples included two PCBs and table 1 shows the elements of each PCB in a separate column.



2.3 The impact surface

The impact surface is so important in experiment. If the PCB hit the ground hard surface directly, may be damaged or crashed. For this reason, the ground surface is covered with an energy adsorbent surface. This surface should be absorb most of kinetic energy during impact and minimize reflecting energy to PCB and minimized PCB shape deformation. To make this multilayer surface energy adsorbent and avoid surface sink, we used some layers of cotton as cushion and glossine papers as appropriate level. Figure 3 shows details of the designed surface. The thickness and details of each layer is given in table 2.

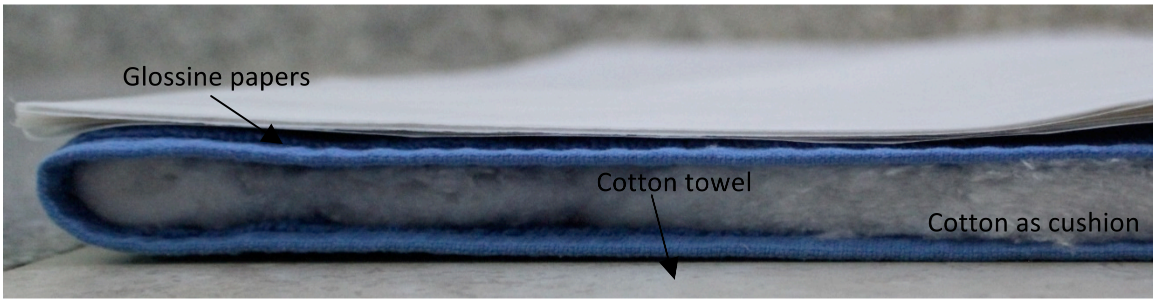


Figure 3: Details of the impact surface structure.

Table 2. Details of impact surface layers.

layer type	components	thickness(cm)
Glossine papers	paper fibers after calendering	18×0.3=5.4
cotton towel	100% Cotton Bath Towel	2×0.3=0.6
cotton	pure cotton	1.5

For measuring falling height and thickness of layers, a ruler with precision one-tenth millimeter per meter is used.

2.4 Tests performed

The tests were carried out from several heights and prescribed samples. The three samples dropped from two different heights for showing exact response of PCB. The drop height is selected to 148.37 and 151.33. Due to elliptical form of PCB profile, the size of samples are given in table 3.

All samples dropped from two heights respectively, it means that firstly we dropped the sample from height1, instantly we repeated dropping from height2. At the start of stage1 and end of stage2 we measure the weight of all samples and results are given in table 5. Twice dropping is better than one drop because the weight changes appear better. The time between start and end of each drop is 0.55 second and the impact velocity is approximately 5.4 m/s.

Table 3. Details of samples dimensions.

	sample 1	sample 2	sample 3
Length (cm)	30.5	30.5	30.5

Major axis (cm)	3.7	3.2	3.2
Minor axis (cm)	2.5	2.05	2.05

Table 4. Weight change related to type of samples and height.

	sample 1		sample 2		sample3	
	before drop	after drop	before drop	after drop	before drop	after drop
height 1 (cm)	148.37	0	151.33	0	151.33	0
height 2 (cm)	151.33	0	148.37	0	148.37	0
weight (gr)	44.329	44.506	35.362	35.28	35.676	35.7
Weight change (gr)	-0.177		0.082		-0.024	
Weight change (%)	-0.399%		0.232%		-0.067%	

From table 4 and 1, it can be seen that the weight behavior is affected by the distribution of energy in structure during and after impact. The distribution of energy is related to some parameters such as type of elements and its purity in samples, impact surface, and impact force. In sample 2, the two PCBs are similar and approximately pure. Only in this case the weight increase after impact, because the energy wave in the total structure is distributed aligned to the impact force. In samples 1 and 3, the two PCBs are a few different in elements and their purities, so in these two samples the energy wave in the total structure is not distributed aligned impact force. Obviously the weight is decreased after impact and the rate of decrease is related to the percent of impurities in specimen.

In sample 3 the S percent is so low, the weight change is so low too. In sample 1 the Mg percent is higher than S percent in sample 3, in the meantime there is no F in one of the specimen of sample 1 so there are more impurities in sample 1 in compare to sample 3. Following the above details, the weight change in sample 1 is about six times more than sample 3.

3. THE CONCLUSION OF THE EXPERIMENT

If a structure affected by force, the energy waves distributed along force direction. If the structure cause these waves distributed directly the weight is increased and if the energy waves divert from the force direction the weight is decreased that this reduction is related to rate of diverge. Based on this idea, we able to give an acceptable explanation of crack zone in [13].

All panels in figure. 4 (ref to fig. 9 of [13]) fractured at three locations: first, slightly below the mid-height of the panel is fractured then the bottom and near the top of panel is cracked. In fact the energy waves are distributed in top and middle parts of UHPC panel directly which was aligned to a 2.05-MPa-ms impulse. The energy waves distributed from two locations at top and bottom, reached in the mid-height and their effect on each other is deviation from impulse direction. This deviation, caused to weight and related to it, strength loss, so the panel was broken firstly in this area. The mechanism of breaking in top and bottom is different. In these areas the energy waves is so dense. After breaking mid height, a discontinuity in energy wave is happened exactly at the junction of panel and restraint, so weight and energy difference between the middle and junction areas is augmented and panel fractured at junction areas.

4. SUMMARY AND CONCLUDING REMARKS

We have evaluated the behavior and weigh change of PCBs in falling from height. A complete test is designed and all details of structure elements was considered during experiments.

The weight of different samples made of two PCBs, was measured before and after falling. For augmentation of weight change, each sample fall twice from different heights. Comparing the weight differences before and after falls, shows the effect of impact force and impact energy in changing weight.

The results showed the effect of elements purity and the percent of impurities in the rate of weight change. If the sample two PCBs were similar and approximately pure, the weight increase after impact, because the energy wave in the total structure was distributed aligned to the impact force. This weight changes can be used to explain the fracture reason after impact.

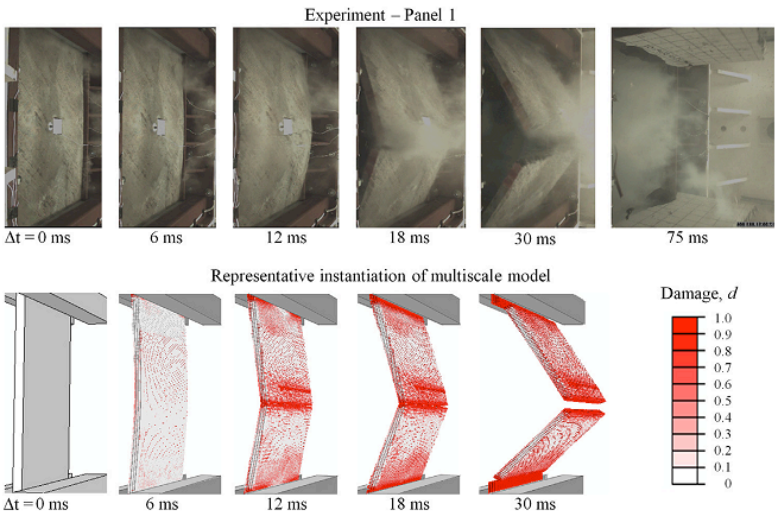


Figure. 4. Images of UHPC Panel and one instantiation of the multiscale model subjected to a 2.05-MPa-ms reflected impulse. Both the experiments and numerical simulations show three areas of fracture, one at the mid-height, and two in top and bottom restraint.

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