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Experimental Analysis of Coefficient of Restitution in Impacts

A.V.Phanse[1], N.A.Barve[2]
Assistant Professor[1], PG Student[2] , Department of Mechanical Engineering[1,2],
Gharda Institute of Technology, Lavel[1], Finolex Academy of Management and Technology, Ratnagiri[2]
Email: aviphanse@gmail.com[1] , nayana.barve@gmail.com[2]

Abstract- The impact of spheres is the fundamental problem in engineering and its applications. The effect of impact is characterized by coefficient of restitution (COR). COR value depends upon various parameters. This paper deals with experimental analysis of impact of spheres with aluminum surface. Different methods are studied to determine COR experimentally. Experiments are carried out to find COR for various configurations of experimental parameters. The effect of ball diameter, material of ball and initial release height on COR in low velocity impacts is investigated through experiments.

Index Terms- Impact, Coefficient of restitution,

1. INTRODUCTION

Impact is the phenomenon of collision of two bodies which occurs in a very short interval of time. During impact, the two bodies exert a very large force on each other. Generally, bodies repel each other after impact due to elastic property. This kind of change in rigid body motion can be evaluated from macro-mechanical impact properties such as coefficient of restitution and contact duration of the impacting bodies.

The effect of impact is mainly characterized by coefficient of restitution (COR). The coefficient of restitution is defined as the ratio of relative velocity of bodies after impact to the relative velocity before impact, and denoted by 'e'. The COR generally lies in between zero to one. When the COR is zero, the impact is fully plastic and when this is one, then it is fully elastic. In case of elastic collision, both momentum and energy are conserved. Thus, the kinetic energies before and after impact are equal. But, in actual practice COR is neither zero nor one. This value depends upon factors such as release height, impact velocity and contact duration etc. The coefficient of restitution has large number of significant applications ranging from macroscopic mechanical engineering to microscopic particle technology. Being a basic and fundamental problem in engineering a lot of research and work has been carried out on collisions and coefficient of restitution.

A.Aryaei et al. [1] analyzed COR in low velocity impact. Impact experiments were performed in a drop test apparatus. Steel and aluminum balls are placed at the top of wooden frame and dropped on steel sheet. The rebound height of ball is observed using high speed camera. To verify the results obtained from experimental analysis, finite elemental analysis is carried out using ANSYS. In order to observe the effect of balls' size, the modeling and analysis of different steel balls dropped on steel plate is carried out. Plates and balls were treated homogeneous and isotropic. Two different shapes were used for ball meshing; viz. brick and tetragonal shapes. For sheet meshing, brick shape elements were used. It is observed that the ball size has more significant effect on COR in impacts between a ball and a sheet made from different materials than in those occurred between a ball and a sheet with the same materials.

Hirofumi Minamoto et al.[2] studied impact between two identical steel spheres. Sphere of typical light metal, aluminum (JIS A5052) are used for experimentation and compared the impact properties with those of SUJ2 steel. Two different setups were used for the experimentation depending on the impact speed. For low speed impact, the spheres were impacted by pendulum setup. The angles of pendulum before and after impact are measured and coefficient of restitution is calculated. For high speed impact, spheres were impacted by air gun setup. The initial speed of impacting sphere and post impact speed of the both spheres were obtained from the time of the pulses and the distance between the photo transistors. The impact of spheres is simulated using LS-DYNA. It is found that SUJ2 sphere has higher coefficient of restitution than A5052 sphere.

N Farkas and R D Ramsier [4] experimentally studied various techniques to measure coefficient of restitution. They dropped various types of balls from a known height (ho). The total time from release to stop of bouncing is measured using stopwatch. It is seen that, more elastic the ball, the longer it bounces.

Ajay Wadhwa[5] analyzed the existing methods and introduced a new method of determining coefficient of restitution using a digital

oscilloscope. A ball of mass m is dropped from initial height h on a horizontal hard surface. As the ball falls from the rest position at known height to collide with the surface below, it produces a distinct sound. This sound of impact is detected by the microphone of the electronic circuit and converted to an electrical signal which is filtered and then amplified. The time interval between two successive impacts is observed. The value of the COR is determined by plotting a graph of the values of the time interval between the two impacts against the square root of the initial heights from which the ball is dropped.

2. EXPERIMENTAL ANALYSIS

Success of any research work depends on the proper planning and execution of the experiments. To logically analyze the data obtained after conduction of experiments, it is necessary to scientifically plan the number of experiments required to be carried out. Based on the various analysis methods studied, total 3 numbers of parameters are finalized for conducting experiments to identify their effect on COR.

Table 2.1 Configuration of experimental parameters

No.	Parameters	Levels			Unit
		1	2	3	
1	Ball material	Steel	Copper	Lead	-
2	Ball diameter	5	3	2	mm
3	Initial release height	300	200	100	mm

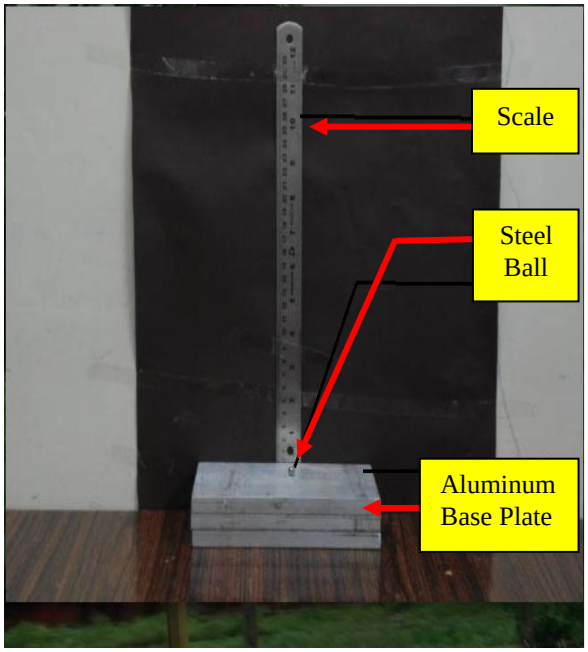

Fig.1. Experimental Setup

Experimental setup is done as shown in fig.2.1. Aluminum base plate is used as a surface. The balls of different sizes and different materials are dropped on aluminum base plate with various initial release heights. The motion of the ball is recorded using a DVD recorder. Using slow motion mode of the film, rebound height of a ball is noted.

Three types of experiments were performed to observe effect of ball diameter, ball material and initial release height separately. To observe effect of ball diameter on COR, steel balls of three different sizes are dropped from same initial release height. To observe effect of ball material, steel, copper and lead balls of same diameter are dropped from same initial release height. To observe effect of initial release height, steel ball is dropped from three different initial release heights on a base plate. The rebound height is noted for all the tests and COR is found out for all the cases.

Assuming no air resistance and only vertical motion, and using conservation of mechanical energy

$$\frac{1}{2}mv^2 = mgh$$

$$v = \sqrt{2gh}$$

From the relation, it is observed that velocity of a ball is function of initial release height. The coefficient of restitution is ratio of final velocity after collision (v_f) to the velocity before collision (v_i). Therefore, it can be expressed by the relation

$$e = \frac{v_f}{v_i}$$

$$e = \left(h_f / h_i\right)^{\frac{1}{2}}$$

Using this relation COR is calculated for all the tests

3. RESULTS

The following tables show results for the various tests conducted to find the relation of ball diameter, ball material and initial release height on coefficient of restitution.

Table 3.1 Experimental results for different ball sizes

Sr. No.	Description		Initial release height (h_i) (mm)	Final rebound height (h_f) (mm)	Coefficient of restitution e
	Material of ball	Diameter (mm)			
1	Steel	2	300	50.67	0.5447
2		3	300	51.33	0.4933
3		5	300	30	0.411

Table 3.2 Experimental results for different ball materials

Sr. No.	Description		Initial release height (h_i) (mm)	Final rebound height (h_f) (mm)	Coefficient of restitution e
	Material of ball	Diameter(mm)			
1	Steel	2	300	30	0.4509
2	Copper	3	300	53.33	0.3162
3	Lead	5	300	21.33	0.266

Table 3.3 Experimental results for different initial release height

Sr. No.	Description		Initial release height (h_i) (mm)	Final rebound height (h_f) (mm)	Coefficient of restitution e
	Material of ball	Diameter(mm)			
1	Steel	5	300	50.67	0.411
			200	38.67	0.4397
			100	29.67	0.5447

The graphs of the above experimental work are plotted to investigate the relationships. Following are the graphs which shows the change in value of COR with changing process parameters.

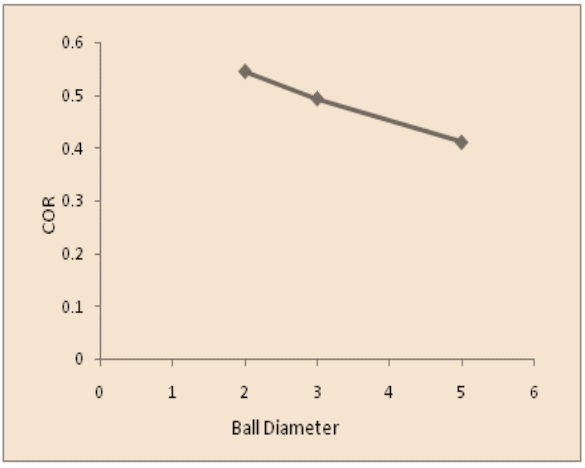

Fig.2. Effect of change in ball diameter on COR

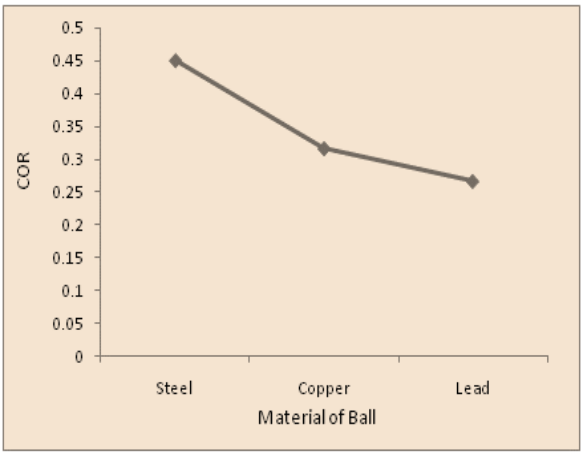

Fig.3. Effect of change in ball material on COR

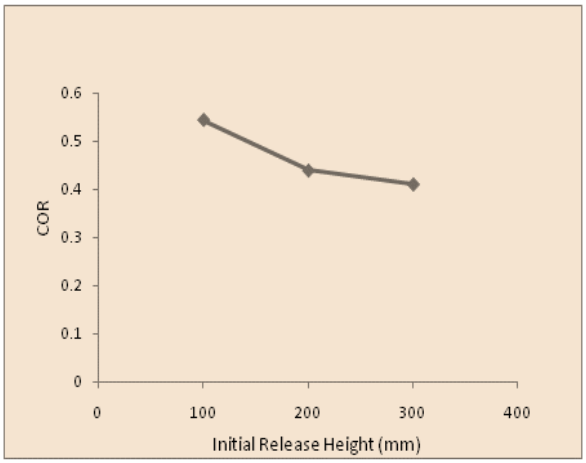

Fig.4. Effect change in initial release height on COR

4. CONCLUSION

The effect of ball diameter, material of ball and initial release height on COR in low velocity impacts is investigated through experiments.

Based on the present experimental results and graphs thus plotted, it is observed that COR decreases with increase in diameter of ball and initial release height. Also it is observed that steel has highest COR than copper and lead.

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