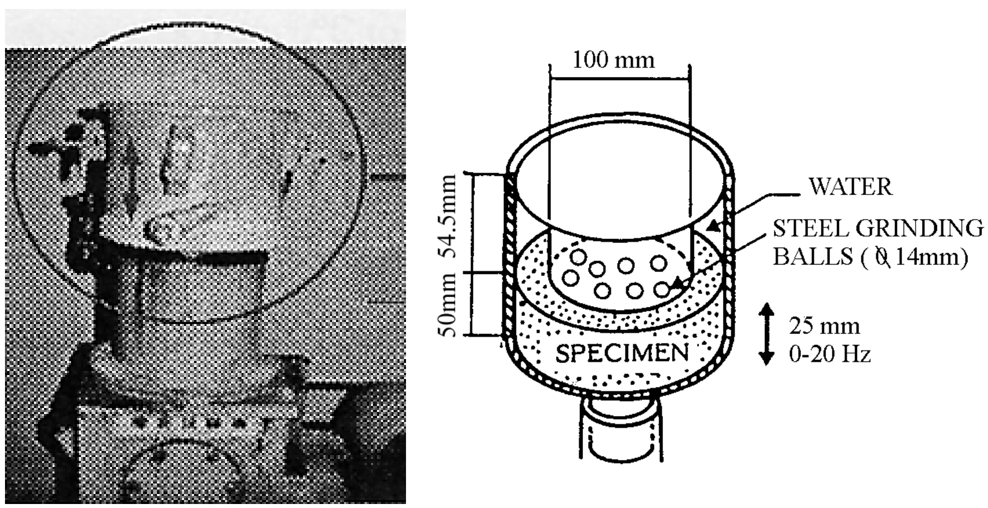
Appendix U.2.6 – Horiguchi's bouncing balls

Generic Name of Test	*Impacting* Steel Balls (in Water) : Abrasion / Erosion Test
Principle of Test	Steel balls bouncing up and down in water.
Historic Development of Test	The test appears to have been used previously by Barou in France (1975) and by Liu in America in 1981. Its official name may be '*Wear resistance of concrete under low temperature using bouncing steel balls in water/methyl alcohol.*'
Apparatus and Abrasives	The apparatus is shown in figure U.2.6.1. It consists of a mechanical shaker, which holds a disk shaped concrete specimen (Ø150mm x 50mm), 8 steel balls 14mm in diameter and water or methyl alcohol. The shaker can move vertically up and down approximately 25mm. [Horiguchi (1995)]
 **Figure U.2.6.1** Apparatus used in the testing of concrete at low temperatures [Horiguchi (1995)]	
Test Method	A concrete disc is inserted into the shaking device along with the steel balls. Water at the desired temperature (or methyl alcohol for temperatures below freezing) is added and the shaking device sealed. The shaker is run at 480 cycles per minute for an unspecified length of time. [Horiguchi (1995)]
Abrasion Wear	This is measured as the average wear depth in mm. [Horiguchi (1995)]
References	Author — Comment Horiguchi (1994,1995) — Source document Hutchings (1992) — Source document

APPENDIX U.2.6

Wear Mechanisms according to Author

(i) Horiguchi (1995): The concrete surface is worn down by means of the repeated impact action of the repetitive vertical forces of the steel balls, which may be referred to as ‘surface fatigue wear’ or ‘impact wear’ or ‘brittle failure wear’. Essentially the tensile strength of the material is exceeded from the impact and Hertzian cone cracks develop, and this leads to abrasive wear.

(ii) Visual Effects: None available

Wear Mechanisms according to writer [R0 S0 I2]

(i) Impact: The steel ball will first make contact with the high points of the surface and will crush them, as indicated in figure U.2.6.2.

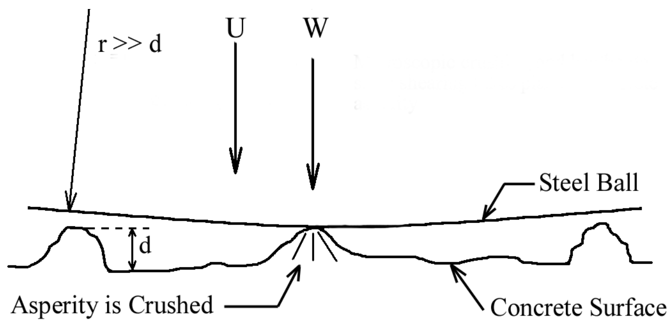


Figure U.2.6.2 The microscopic effect of a relatively mild contact of a ball against a concrete surface

However, with sufficient velocity U, the kinetic energy of the ball completely crushes the asperities and then compresses the concrete elastically at the point of contact. In fact, a whole sub-asperity zone goes into compression, as indicated by zone B in figure U.2.6.3, which represents the Hertzian stress field. It is the release of this elastic energy that causes the ball to bounce.

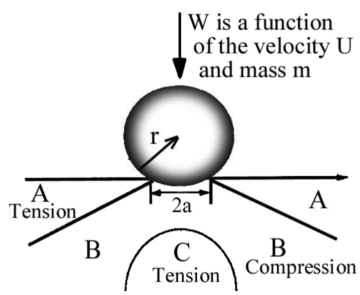


Figure U.2.6.3 Hertzian stress field due to indentation made by ball in concrete surface [Horiguchi (1995)]

(ii) Cracking: This occurs when the contact is sufficiently severe as to cause an indentation deep enough to exceed the tensile strength of the relatively brittle concrete, resulting in a crack the shape of a truncated cone at the interface between the compression zone B and tension zone A in figure U.2.6.3. Lateral cracks and axial cracks may also manifest with further increase in load, but these are unlikely to occur in this test.

According to Hutchings (1992), the abrasion wear is likely to follow the expression $Q_{Impact} \propto \frac{m.U^2}{H} f(\theta)$ where U is the maximum velocity, m is the mass of the ball, H is the hardness of the concrete and $f(\theta)$ is a factor based on the angle of impact (90^0 in this case).

(iii) Adhesion and deformation: See note 1 in introduction to appendix U