Test device for measuring the strength of eggshells in environmental research

by Peter H. Becker, Christa Koepff and Wilfried Bruns

Monitoring the effects of environmental contamination is becoming more important, particularly in developed countries where wildlife is at risk. Rivers present a particular problem because they may pass through polluted regions on their way to the sea, carrying contaminants to coastal areas which are remote from the source of the pollution. The measurement and correlation of the effects of contaminants often involves complicated equipment. In this article the authors describe how they compared the effect of pollution on the breakage strength of eggshells for two species of seabirds taken from different locations on the German North Sea coast. The measurement equipment used to measure the eggshell deformation is remarkable in its simplicity, consisting only of a force transducer, a displacement transducer and the actual loading device.

Introduction

Birds are particularly sensitive to pollution during the reproductive period, because many chemicals in the environment accumulate in the egg. In the case of lipophilic contaminants which dissolve in fat, the decrease in the fat stored in the egg yolk during the development of the embryo leads to a further increase in concentration. If critical limits are exceeded, this can in turn cause the death of the young during the hatching process. The insecticide DDT (dichlorodiphenyltrichloroethane) and its metabolites also cause the eggshell to be thinner than normal, which leads to egg breakage and subsequent loss of the brood. It was for these reasons that the populations of birds of prey and seabirds in the industrial countries sharply decreased in the '60s and '70s when DDT was vigorously applied [1, 2, 3].

Apart from the measurement of the thickness of the eggshell, testing the resistance to breakage is also a sensitive method of analyzing changes in the eggshell. Reductions in the breakage strength of eggshells correlate positively with trace quantities of various pollutants [4, 5, 6]. This parameter can be found with expensive materials testing machines [7], but an economical measurement device has been recently described by Picman [8].

Pollutants in the eggs of two common coastal species of birds - the oystercatcher (Haematopus ostralegus) and the common tern (Sterna hirundo) - have been examined [9]. This work was included in a research project from the Institut für Vogelforschung, sponsored by the Umweltbundesamt and carried out in cooperation with the Chemischen Institut der Tierärztlichen Hochschule in Hanover.

The eggs were obtained from locations along the German North Sea coast. The locations were selected such that geographical differences could be found in contamination and in the significance of pollutants brought into the North Sea by rivers. Samples taken over a number of years should also produce information about time trends.

The most severely contaminated eggs were found to be those of the common tern from the Elbe estuary where particularly high concentrations of mercury and

Fig. 1: Three-egg clutch of common tern eggs.

polychlorinated biphenyls (PCBs) occur [9, 10, 11, 12]. They exceed critical values, putting the breeding of the birds in the region of the Elbe estuary at risk. **Figure 1** shows a common tern nest.
An investigation into the relationships between the following parameters, including a comparison of eggs

of birds breeding in a less contaminated region was regarded as being important:

- the quality of the eggshell, i.e. the thickness and breakage strength
- the success in hatching the eggs
- the quantities of pollutants in the eggs.

The procurement of an expensive materials testing device was not considered due to the cost involved. In cooperation with the Labor für Werkstofftechnik Fachbereich Maschinenbau der Fachhochschule Wilhelmshaven a simple, economical, but nevertheless exact device for the measurement of eggshell breakage strength was developed. This article deals with this development.

Description of test equipment

Specification

The test device should enable a load to be applied to the egg under controlled deformation. During the test the loading force applied to the egg must be measured in relationship to the deformation of the egg up to the point of cracking. From a number of proposals it was decided to adopt a test system which would enable a test result in the form of a force-deformation curve to be obtained at the end of the test. The test procedure was to be carried out by measuring the applied force up to the destruction of the egg, i.e. the point of cracking. The resulting deformation can be read off the X-Y graph with the required accuracy.

Design of the device

Figure 2 is a sketch showing the basic design of the test device. The egg to be tested is placed on a testing table which is mounted on the force transfer part of a force transducer. The force transducer is bolted onto the device's stand and it measures the force applied to the egg from above. The load on the egg is produced by a manually operated crank which pulls a lever downward via a spindle. The lever loads the egg via a plunger which has a pressure plate attached at the lower end. **Figure 3** shows how the egg is placed in the test device; the positioning of the transducers for force and displacement can also be seen in this illustration. The thread pitch on the spindle and the lever ratio produce a vertical movement of 0.175 mm (0.007 in) on the precision guided plunger for each crank revolution.

A Z8 Force Transducer with a nominal force of 100 N (22.5 lbf) is used for the force measurement. The transducer contains a full-bridge strain-gage circuit in thinfilm technology. This circuit is supplied from an MGT 31 DC Measuring Amplifier which also processes the bridge signal. The deformation measurement is made by a W 10TK Inductive Displacement Transducer having a nominal displacement of 10 mm (0.4 in). The displacement transducer measures the displacement of the plunger, giving a measure of the deformation of the egg.

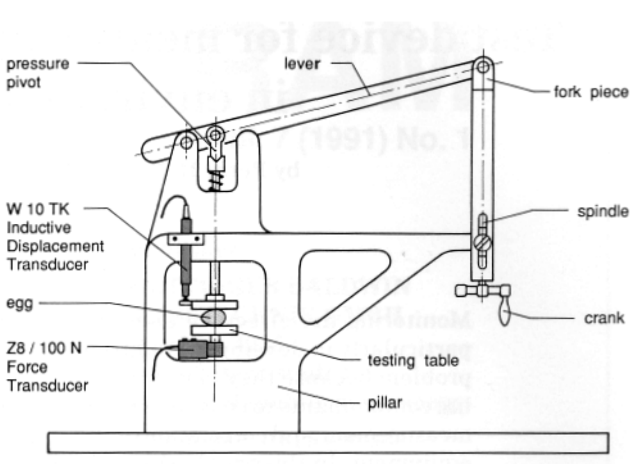

Fig. 2: Diagram of the device which was developed for testing the breakage strength of eggshells.

The displacement transducer signal is processed by a 5 kHz Carrier Frequency Measuring Amplifier, type MGT 33 which also provides the supply voltage. Both of the amplifiers, the MGT 31 and the MGT 33, each of which contains a peak value store as an additional function unit, are accommodated with a CMP 16 Display Interface in one common housing. The peak values which arise during the process can be recalled using the peak

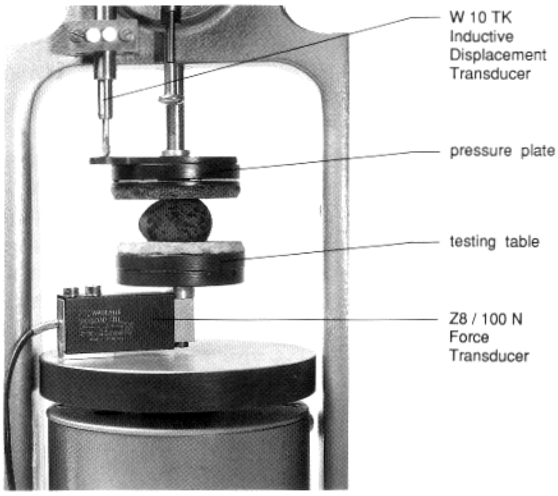

Fig. 3: Mounting arrangement used for the Z8/100 N Force Transducer on the testing table and for the W 10TK Inductive Displacement Transducer which was mounted on the pressure plate of the test device.

value store. The maximum force acting on the egg during the deformation-controlled load test can therefore be stored. The analog output signals from both amplifiers are passed to an X-Y-recorder which registers the deformation characteristic and the onset of fracture for the tested egg as a force-displacement diagram. The test curve is produced during the test in an appropriate

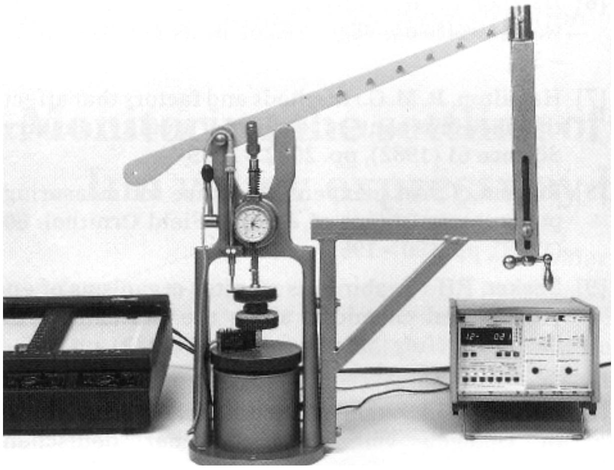

Fig. 4: Overall view of the test equipment with the two-channel measuring amplifier for processing the force and displacement signals. An X-Y recorder for displaying the force-deformation curves is also shown.

scale depending on the calibration. **Figure 4** is a photograph of the complete test device with the two-channel amplifier and the X-Y recorder.

The method in practice

During the course of preliminary trials using chicken eggs and during the actual tests, experience was gained about the procedure which must be taken into account if valid results are to be obtained:

- The eggs must always be placed lying horizontally on the testing table. A foam rubber ring on the edge of the table prevents the eggs from rolling off, but it does not affect the testing conditions.
- Grains of sand or blades of grass adhering to the surf ace of the egg at points which will come into contact with the pressure plate must be carefully removed before the measurement. Otherwise they may modify the surf ace of the egg, impairing the measurement results.
- During each measurement the eggshell was only deformed in the immediate vicinity of the relevant measuring point. With the relatively small common tern eggs (see below for dimensions) the breakage strength of the eggshell could normally be found at three different points about the egg's equator, whereas up to five measurements could be made with the larger oystercatcher eggs. Attention was given though to ensure that the measuring points were distributed at angles less than 180° around the egg so that the points of contact did not coincide with other measurements made on the same egg.
- The speed at which the manual crank was rotated did not alter the slope of the curve nor its maximum value. However, the rotational movement should be carried out as smoothly as possible as any hesitation shows up as an irregularity in the curve.

Results

No differences were found in the breakage strength between the two areas under investigation, i.e. on the Elbe (Hullen) and on the Jadebusen (Augustgroden). The measurements made for both regions are shown summarized in **Table 1**. Values for the mean, standard deviation, maximum and minimum are shown for the breakage force and associated deformation as well as for the

Common tern eggs		Augustgroden (n = 10)	Hullen (n = 36)
fracture force in N	mean	4.95	4.78
	standard deviation	0.90	0.91
	maximum value	6.73	7.34
	minimum value	3.66	2.54
deformation in mm	mean	0.143	0.138
	standard deviation	0.027	0.019
	maximum value	0.186	0.177
	minimum value	0.106	0.086
shell thickness in μm	mean	194.2	194.1
	standard deviation	10.35	11.44
	maximum value	213	210
	minimum value	180	170

Table 1: Comparison of measurements carried out on eggs of the common tern from the areas Augustgroden (Jadebusen) and Hullen (Elbe estuary).

shell thickness. There was no definite difference found in the force and displacement values required to break the eggshell. Also, the thickness of eggshells did not differ between the two regions. The main pollutant causing thinning of the eggshell, DDT, had a higher concentration in the eggs at Hullen than in Augustgroden (0.67 mg/ kg, respectively 0.23 mg/kg), but these values are below

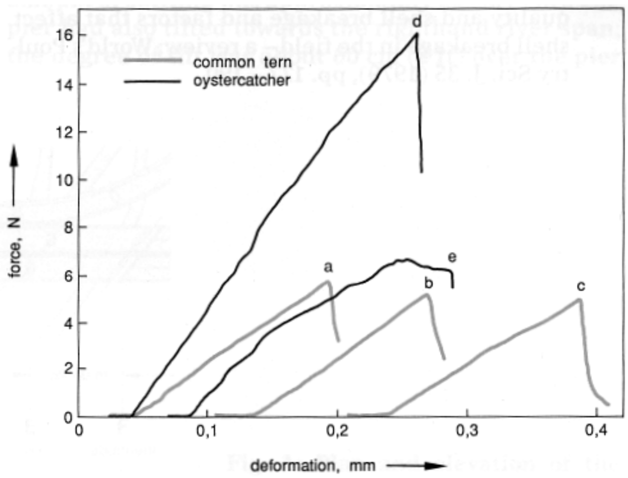

Fig. 5: Examples of the force-deformation curves measured for the eggs of the common tern and the oystercatcher.

the accepted critical value of 25 mg/kg for shell production by the common tern [13]. **Figure 5** illustrates summarized examples for the resulting force-displacement graphs. It can be seen that substantial point forces can be applied to the eggs of the oystercatcher and the common tern, producing average forces of 13.8N (3.1lbf) and 4.8N (1.1lbf) respectively. The egg of the oystercatcher is significantly larger than that of the common tern and the shell is thicker; it can therefore withstand significantly greater loads (oystercatcher egg approx. 55 mm long, 40 mm wide, 0.3 mm thick [2.2 x 1.6 x.012 in]; common tern approx. 42 mm long, 31 mm wide, 0.2 mm thick [1.7 x 1.2 x .008 in]). The curves labeled a, b and c show the results for one egg of the common tern and the curves d and e were measured on two oystercatcher eggs. Curve e indicates a lower eggshell strength and the modified force-deformation characteristic when compared with curve d suggests that curve e represents a "cracked egg", i.e. an egg, the shell of which was already cracked before the measurement.

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Dr. rer. nat. Peter H. Becker is a member of the scientific staff at the Institut für Vogelforschung, Wilhelmshaven, FRG working in the field of ecology and pollutant contamination of seabirds. He is leader of the project "Seabirds as monitors of environmental chemicals". **Dr. rer. nat. Christa Koepff** is a scientist employed on the above project. **Wilfried Bruns** is a laboratory engineer in mechanical engineering at the Fachhochschule, Wilhelmshaven.