by the old and well-tested principles of love to their neighbours, of democracy, and all the ethic laws, appropriate for leaders in Science and Society.

We hope that our future collaboration will open a new path between the Royal Society of London and our Academy in exchanging ideas and knowledge between the two old and learned Societies, for the progress of Science and development of our peoples.

With a great pleasure and deep emotion I bestow to you the great insignia of the Full Fellow of the Academy of Athens.

And then I invite you to deliver your discourse on a subject, which is very dear to you, and which is entitled: «Aspects of Metal Plasticity».

Παρακαλῶ τώρα, ἀγαπητὲ συνάδελφε, ὅπως λάβετε τὸν λόγον καὶ ἀναπτύξετε τὸ θέμα σας τὸ ὁποῖον εἶναι ἀπὸ τὴν περιοχὴν τῶν ἐρευνῶν σας καὶ σᾶς εἶναι ἐξόχως ἀγαπητόν. Ὁ τίτλος τῆς ἀνακοινώσεως τοῦ κ. Johnson εἶναι:

«Ἀπόψεις ἐπὶ τῆς Πλαστικότητος τῶν Μετάλλων».

ASPECTS OF METAL PLASTICITY

ΟΜΙΛΙΑ ΤΟΥ ΞΕΝΟΥ ΕΤΑΙΡΟΥ ΤΗΣ ΑΚΑΔΗΜΙΑΣ

Κ. WILLIAM JOHNSON

President, Members of the Academy, Ladies and Gentlemen,

First, I want to say how very pleased I am to be associated with this great Academy which has its roots in the philosophy of Plato and in the magnificent science of Aristotle and numerous other great ancient men. I must thank you warmly for electing me to your internationally renowned and illustrious Academy. In making me a Foreign Fellow it is a very great honour that you confer upon me and it is one in which I shall always take great pride. Also, in selecting an Englishman, the very special historical and cultural relationship between our two countries is underlined. Especially are the political, and the intellectual and scientific origins of the life of our two democracies to be found in Ancient Greece. Democracy is the o n l y *possible political form for independent and thinking people as you know from your recent history and Britain knows from its involvement in the Falkland Islands War.*

I will now speak about my own special studies, interests and research contributions, mainly to the Mechanics of Metalforming Plasticity — an applied science which is only possible to-day after the foundations and fundamental work of Euclid, Eudoxus, Archimedes and such great persons.

I apologise for continuing now in English.

INTRODUCTION

Scope

I shall first describe some industrial processes which are very important for maintaining our daily life at its present level of comfort. They are concerned with changing the shape of metal sheets, plates and bars by using methods which have been well established for several decades and sometimes centuries. I shall then describe newer processes which have been introduced because they are faster or give a better and cheaper product. To achieve improvements a good understanding of the mechanics of the process is usually required and this has only recently been achieved. I conclude by extending the subject to show how it encompasses studies in respect of the safety of our environment.

Metal Forming Presses, Mills and the like

Thousands of large sheets of thin metal are stamped or pressed out every day to provide items such as motor car panels, bath-tubs and pans. The presses used can be very large and are usually extremely expensive. The sheet is initially rolled to an appropriate thickness by starting from short, thick ingots. Sometimes however, the metal is extruded to provide rods of great length and complex cross-section, e. g., for window-frames and tooth paste tubes, or pulled through dies to form round wire or thin tube. The hammering or forging of hot or cold metal to change its shape is perhaps the oldest known process. Indenting and coining are associated common ancient processes. The ingenuity of Man is very great when we consider seriously his ability to devise machines for manipulating or forming hard metals. Fig. 1 shows a large elevated water tank consisting of about one hundred plates, $3\,m \times 4\,m$, individually pressed and then welded together for holding about $32{,}000\ m^3$ of water and is a specific example of metal plate pressing.

The Need for a Science of Metal Processing

To achieve the structure shown in Fig. 1, each plate must be pressed into a carefully designed die so that after removing it, it will have the shape required: after taking it out of the die the metal tries to spring back elastically towards its initially flat shape. To pre-determine shape-perfect pressings econo-

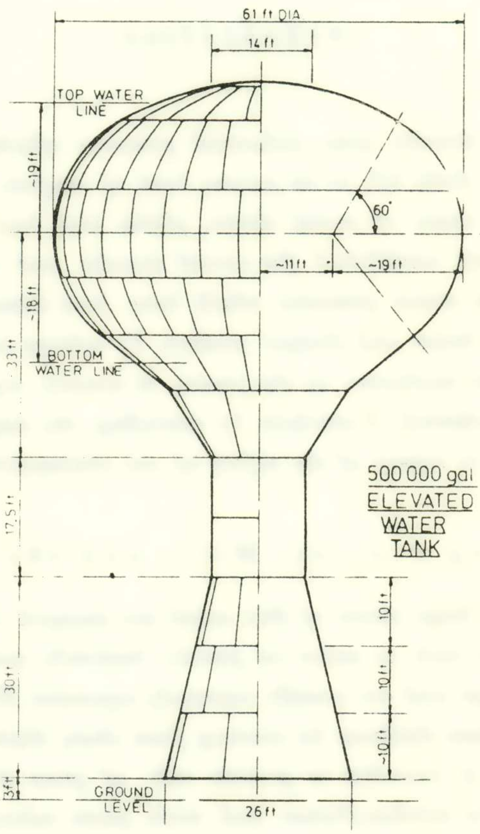

Fig. 1. A half-a-million-gallon elevated spherical watertank for erection in Saudi Arabia.

mically we need to know how to measure the strength of the metal and its elastic and plastic properties. Armed with applied mathematics we can then dimension the punch and the die and also calculate the powerfulness of the press required to force the punch into the die and thus shape the plate.

In performing all the necessary mathematical calculations equations pertaining to stress, force or moment equilibrium, stress-strain increment relations *and a yield criterion for the particular metal used must be satisfied in accordance with given or specified boundary conditions. Many equations require to be solved to adequately design the dies (which may be rough and introduce friction) and to prescribe the press or mill required; indeed, sometimes as many as ten are accumulated. Frequently this task proves too difficult and to make matters easier, helpful realistic assumptions are made. Also, specific mathematical techniques*

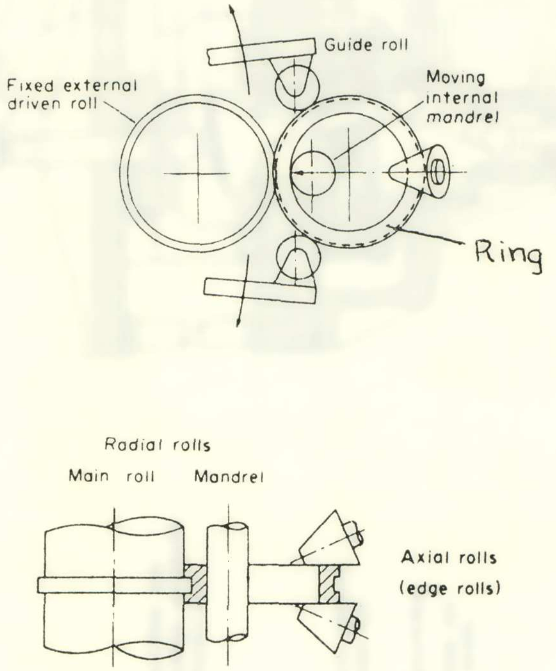

Fig. 2. The basic components of a ring-rolling mill.

may be adopted, e. g. the theory of slip line fields, or an approach which is called load bounding. Details of the theoretical mechanics employed are representatively presented at length in refs. 1 and 2.

Many very important facets of the physics and mechanics of metal processing which are of abundant practical importance, e. g., residual stresses in the processed metal, its fatigue life and integrity, cannot be described here for want of space.

It must also suffice to refer the reader to well known monographs for further insights but to note that success and economy in production in the modern world depends upon both scientific theory and practical ingenuity.

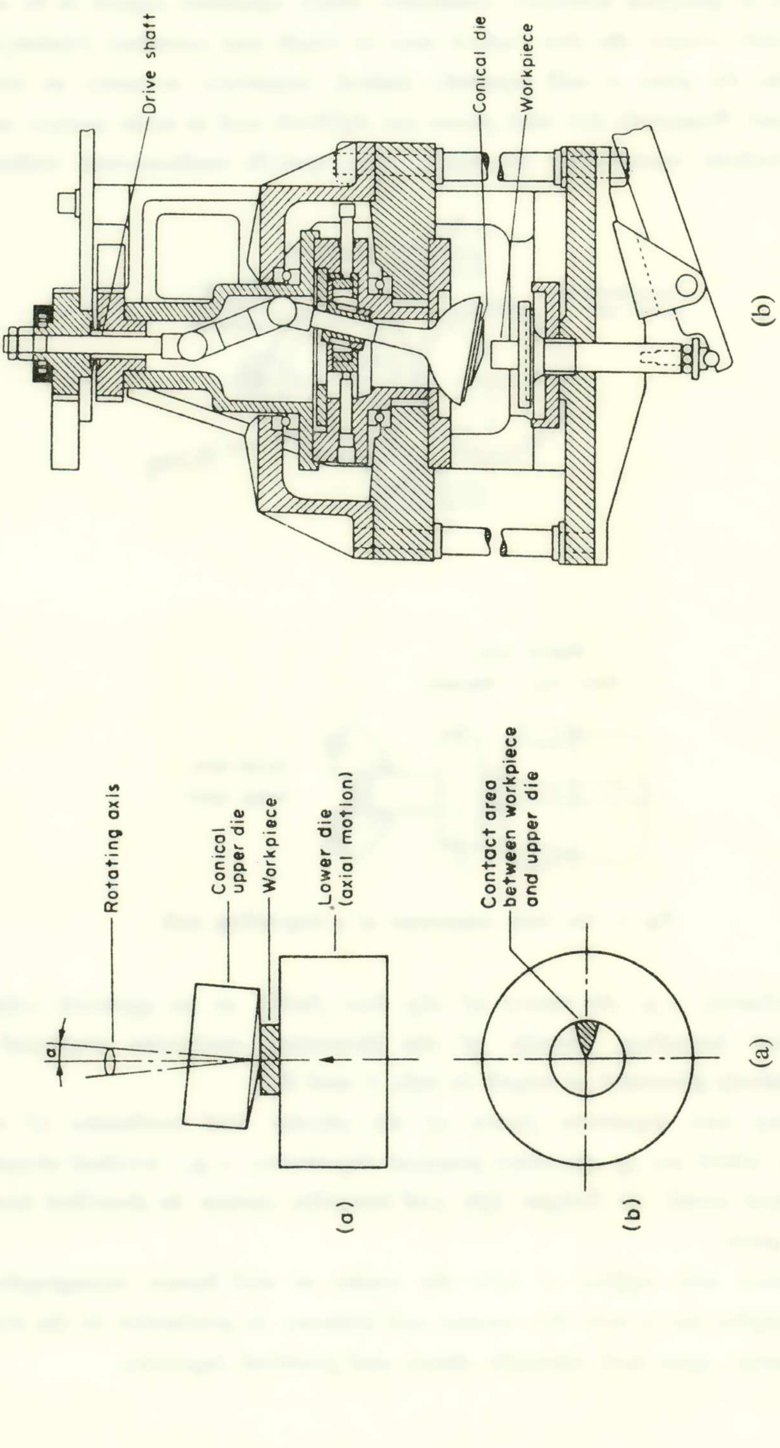

Fig. 3. (a) The principle of rotary forging. (b) A small scale model of a rotary forging machine.

Newer Forming Processes

Three interesting processes that have been developed over the last decade are :

(i) precision cold rolling of rings, Fig. 2,

(ii) development of rotary forging machines, Figs. 3(a) and 3(b) and

(iii) shot-peen forming; small shot bombards a metal plate, see Fig. 4, and causes its surface to harden advantageously and to take up the typical shape of a wing.

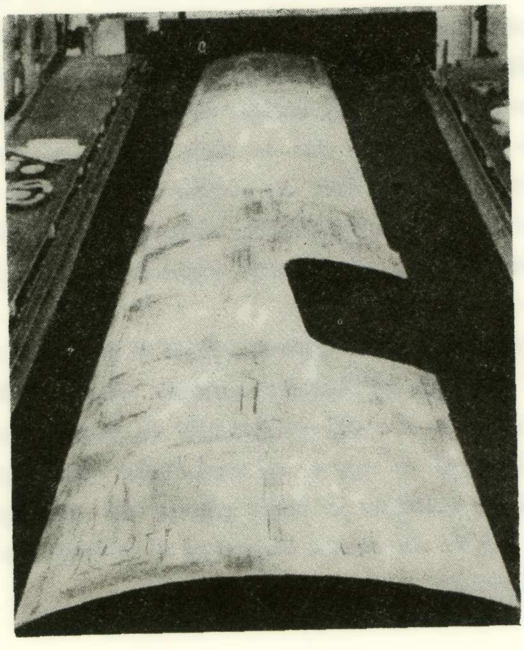

Fig. 4. A long wing panel after shot-peen forming.

Subsiduary to these processes, industrial engineers have recently devoted their attention to trying to reduce the noise levels associated with some forming processes, to using less (costly) energy when processing material, to reducing material wastage and to decreasing the amount of human handling of metal in or near presses (often in oppressive environments), by the use of robots.

A few years ago there was developed the use of high explosives detonated under water, so that the shock waves thus radiated could act on plate and so deform it as required, into a die. This is now commonly carried out. Explosives are also used for welding together plates. Similar shock loading procedures have been engineered where the shock is due to a pulsed electro-magnetic field, the explosion of common gases and high-voltage electrical discharges under water.

The Extension of Metal processing Studies to Impact Engineering

The last-named processes are collectively referred to as High Rate Forming and in terms of mechanics require the inertia of the metal to be considered. In a not too dissimilar manner and employing the principles earlier outlined, the plastic deformation undergone by bullets on impact, see ref. 4 and the large scale deformation of buildings due to blast, (e.g., due to an internal gas explosion or an external one from a nuclear bomb), can be accounted for. Neglecting inertial effects and considering them as slow speed impacts, the area of research "Crashworthiness of Vehicles" (motor cars, aircraft, ships and railway trains), see ref. 3, has grown up.

For very high speed impacts delivered from shaped-charged jets (6000 m/s) or in the form of long rods of depleted uranium (fired at 2000 m/s), to penetrate armoured vehicles, it is usual analytically to treat the metal as if it was a fluid. This is discussed in ref. 4. At even higher speeds of impact, as when meteoroids hit orbiting satellites or make craters like the huge Barringer crater in Arizona in the U.S.A., the energy dissipated is so large that the impact event is effectively an explosion.

CONCLUSION

Aristotle (in translation) observed that "knowledge of a fact is different from knowledge of the reason for a fact". I have described many facts and processes relating to changing the shape of metal. Today we are also in the happy position of being able to explain them with the aid of the mathematics, mechanics and physics originally developed in and about Athens two and one half millenia ago.

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