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THE 'INCLUSIVE ENGINEERING' APPROACH: AN OPTIMUM DIAMETER FOR EASE OF OPENING

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ABSTRACT

Social equality demands a shift in attitude, away from treating older people and people with disabilities as special cases requiring special design solutions, and towards enabling them to have equal access to any product or service through a more inclusive approach to the design of buildings, public spaces and, more recently, products and services. This is not just important for social equality but also for business growth through new products and services and through creating wider potential markets.

It is a sad fact of life that as people get older there is a massive decline in their strength and dexterity. Due to the fact that we handle and manipulate so many things throughout our life time, from the tiniest and most dexterous of tasks to heavy manual labour, this decline is very noticeable in our hands. In nearly all the actions that we use our hands for there is some form of grip used in order to hold onto an object before manipulating it. The natural decrease in strength combined with debilitating illness such as arthritis, means that hand grip strength or finger grip strength are very seriously affected. This has a knock on affect of making it much harder to twist things or pinch and pull things. Therefore there is often a measured decrease in torque strength with age caused not so much by a decrease in wrist strength but more often than not by a decrease in grip strength.

Consumer packaging is a field in which many people, including young able bodied people, often struggle in relation to openability. Yet it is present in even the most mundane and neccessary of every day tasks such as eating, cleaning teeth, even drinking. Human interation with consumer packaging requires a wide range of hand dexterity and strength and a variety of differing hand actions. This paper looks at just one such set of actions; that used to open bottles and jars. It outlines all the arguments for inclusive design, stressing the importance for both consumers and business. This paper also outlines an engineering design approach for inclusive design that uses real human factors as design limits, resulting in packaging that will be easily opened by all it's end users without the expensive trial and error approach that has been used up to this point in time. This paper examines the affect of grip strength on the required trorque to open closures and concludes that there is an optimum diameter for ease of opening that will decrease the required strength to open such closures.

GLOSSARY

GF305	Industry Standard spirit bottle thread profile.
Cap/Closure	Generic term for screw thread closure for stopping bottles.
Finish	Generic term for glass thread.
ROPP	Roll-on-Pilfer-Proof, common closure type for spirit bottles.
Wadding/liner	Material insert in the top of the closure to create a tight seal between glass and closure.

EPE	A type of liner material.
Wood pulp	A type of liner material.
Over torque	Torque required to turn the closure the wrong way and strip the thread.
Slip torque	Torque required in opening the closure to make the initial movement or the very first slip.
Bridge torque	Torque required in opening the closure to break the pilfer bridges between cap and pilfer band.

INTRODUCTION

'…design for the young and you exclude the old, design for the old and you include the young…'

- *Bernard Isaacs, Founding Director of the Birmingham Centre for Applied Gerontology (1)*

The problems associated with opening packaging have long been documented. However, the drive to overcome these issues has been slow due to the conflict between ease of opening and protecting the packaged product from both structural damage and from environmental attack, demanding both rigidity and good seal integrity.

However, with the current technical capabilities at the disposal of the packaging industry this is no longer an excuse and it is in the interests of not only the consumer but also the manufacturer to supply packaging that is both easy to open and fulfils all other traditional functions of packaging.

With the capability to measure human factors, it is now possible to use these measurements as design limits. This project investigated the current methods of measuring human strength. It was found that, although indicative of trends, this data is not specific enough to use as design limits for specific products.

Variations such as dimensions and materials, need to be accounted for each specific type of packaging. Therefore instruments have been made for the measurements of specific human strengths, such as the grip strength or torque strength used to open specific closures. These instruments will have universal fittings to which can be attached specific closures or materials, of specific sizes and shapes. Once precise data for human strength has been obtained, this can be used as design limits.

An equation describing the opening of the packaging has to be derived, taking account of human forces applied to the outside of the closure and the structural forces resisting opening or sealing the closure on the internal interface between container and closure. Once this has been derived, the terms in the equation have to be given values or ranges of values for given parametric changes in either the components of the packaging and/or the process by which the packaging is assembled. These are found using experimental and/or numerical techniques such as finite element analysis (FEA) Then, by fixing the human strength terms in the equation at levels within the capability of the weakest consumer, the remaining terms in the equation can be optimised to produce a package that can be easily opened. This must then be tested for structural protection of the product, seal integrity and other such functions, again using experimental and/or numerical techniques. This design process is illustrated in the diagram shown in figure 1.

This paper examines this equation in great detail and gives several conclusions about the affects of different human, component and manufacturing parameters on the ease of opening. This paper uses the ROPP (Roll-on-Pilfer-Proof) closure system as an example.

Figure 2 illustrates this closure before and after application to a bottle while figure 3 illustrates a single head capping machine used to apply this closure to a bottle.

SOCIAL MOTIVATION FOR INCLUSIVE DEISGN

Attitudes to people with disabilities are changing. This has largely been due to government recognition of the needs of those sections of society and pressure from societies, charities and people with disabilities themselves (2). One such pressure group called ‘People First’ state (on their website) ‘Jars should be labelled, not people.’ These labels are condescending and enforce damaging stereotypes.

It is recognised therefore that there needs to be a change in perception to think of all other individuals as people, not labels no matter what their colour, age, religion, physical or mental ability. Hence, it is envisaged that this change of attitude will bring about a more integrated and inclusive society.

BUSINESS MOTIVATION FOR INCLUSIVE DESIGN

By 2020, the new consumer will be the 50+ year old (3). Demographic predictions illustrate that by 2020, 50% of the UK population will be over 50 (figure 4). These people will be the wealthiest 50+ generations that the UK has ever seen, commanding a substantial disposable income and hence control a large proportion of the country’s wealth and savings. This wealth needs to be put back into circulation in order to generate jobs and keep the economy healthy. Retired people also have time to spend more money and also the time to shop around and compare products. Products that are physically inaccessible to them will not be on their shopping lists. In order to maximise market potential for a given product, manufacturers should ensure that they are accessible to the weakest person and by doing so, make it is accessible to all people.

There is also a current costs to both industry and tax payer due to accidents caused by difficult to open packaging. Injury litigations and consumer dissatisfaction directly cost the industry whilst 94,000 accidents a year cost the NHS £12 million a year (4). A large proportion of these costs are due to people using knives and such to attempt to open packaging which shouldn’t require a tool at all. The reason a knife is used is solely down to the difficulty of opening.

MEASUREMENT OF HUMAN STRENGTH

The existing research into human strength is indicative of trends only. It is not sufficient for use as precise design limiting factors. The design limits need to be gathered for specific packages.

The typical types of strength that are required in opening a package are pinch strength, grip strength, opening strength, wrist twisting strength, pull strength and many more. For each of these various strength measurements there are different variations based on orientation, fingers used etc. The strength that can be applied to a form of packaging can vary greatly. For instance, in the case of glass bottles and jars, the height of the closure, the diameter of the closure, the material of the closure, the height of the jar and the diameter of the jar will all affect the type of grip that is applied and hence the strength of grip that can be applied. At the University of Sheffield a universal device is being created for measuring grip strength on bottles and jars in which 'jars' and 'closures' of various sizes and shapes can be attached to the device in order to get accurate and specific measurements.

For each specific type of package, the designer needs to work out the types of strength involved. In the case of the ROPP closure system this happens to be a type of grip strength and a type of opening strength. An analysis needs to be carried out to investigate the various types of grip that are applied and the affect these differences have on the opening strength that can be applied. Once this is done a relationship between grip and opening strength for that specific closure can be created and the lowest grip and opening strength is taken as the design limiting factors.

THE ENGINEERING APPROACH TO INCLUSIVE DESIGN

The basis of the engineering approach to inclusive design is on an analytical analysis, deriving an equation that describes the opening of the packaging. This equation must include both human factor terms and structural terms. That is to say the strength of the human is what overcomes the structural forces resisting opening be they frictional, tensile of shearing forces. The terms in this equation are then found using experimental and/or numerical methods. For example, the human factor terms and material properties can be found using experimentation whilst forces between threads can be found using finite element methods. Precise values or ranges of values can be found for each term.

Once this has been done a parametric study can be carried out using the experimental, numerical and analytical models. The parameters of the components and the process by which those components are brought together to create the package are varied and the effect this has on the openability can be determined.

The human factor terms in the equation are then fixed at the lower limits found from the experimental analysis whilst the remaining terms are changed and optimised, based on the findings of the parametric study, to fit with these low human opening forces. The new design of component(s) and/or process are then tested using any of or all three of the analysis techniques for functions such as seal integrity, structural integrity etc. Figure 1 demonstrates how this can be achieved.

THE ROPP EXAMPLE

Figures 5a and 5b show a typical set of forces that a human would apply to the outside of an ROPP closure. The number of points of contact between the hand and the closure will vary from person to person and hence the number of times that the N_A and F are repeated will vary although N_A will always act raidially towards the centre of the closure and F always at a tangent to the circumference to the closure. To simplify this complication, the terms N_A and F will be taken as the sum of all the grip and frictional forces generating the torque. These forces can be resolved to give the opening torque as:

$$T=Fr \quad \text{Equation 1}$$

where:

$$F=N_A\mu_{shc} \quad \text{Equation 2}$$

and hence:

$$T=N_A\mu_{shc}r \quad \text{Equation 3}$$

where:

T = Applied human opening strength
r = Radius of closure
N_A = Applied human grip strength
F = Frictional forces between human skin and closure
μ_{shc} = Static co-efficient of friction between human skin and closure

Between the closure and the glass bottle there is another set of forces that resist opening such as friction between glass sealing surface and liner material caused by the capping head load or friction between closure and glass thread caused by thread rollers and grip of consumer or friction between closure and glass bead at pilfer band tuck under caused by pilfer band tuck under rollers or the tensile strength of the closures pilfer band bridges. Figure 6 shows some of these forces. From the full force diagram the following equation can be derived:

$T = [C\mu_{gl} + (N_A+N_T)\mu_{gc}cos? - N_T cosf\ sin? + As_{flow}\mu_{gc}]r$ Equation 4

where:

T = Torque required to open closure
C = force at sealing surface due to liner compression
μgl= Coefficient of friction between glass and liner
N_A= Applied force from human grip
N_T= Normal force at thread interface
μgc= Coefficient of friction between glass and closure
? = Thread helix angle
f = Angle of N_T to the vertical
A = Cross sectional area of the pilfer bridge(s)
s_{flow} = Flow stress of closure material

Equations 3 and 4 describe what the human can apply to the closure and what the closure requires to open it. These two must equate or equation 3 must exceed equation 4. Unfortunately, more often than not, the situation is the other way around. During the opening process, some of the terms in equation 4 will change state from static to dynamic, such as the friction coefficients and other terms will change value during the opening process such as the compression of the liner material which will decrease as the closure is unscrewed.

Research, FEA (figure 7) and experimental (figure 8) analyses give ranges of values to the terms in both equations. This gives a range of possible values for the opening torque of the bottle (figure 9). The human strength terms are fixed at the lower limits of the weakest consumer group and the remaining terms are changed via parametric study to incorporate these low human strength terms. The new design is then tested for other functions such as openability and seal integrity (figure 10).

ANALYTICAL ANALYSIS

Figures 11 and 12 show the instruments that the torque strength and grip strength that consumers can apply to this specific type of ROPP 30x35 mm closure, were measured on. Figures 13 and 14 illustrate the results for these measurements against age for various diameter closures. The data collection for this study is an ongoing process that will continue for the duration of this project. However, initial trends can be discussed and where there are enough data for a particular set, real numbers can be used as design limiting factors.

In looking at making this packaging accessible to all people, the strength of the weakest target consumer was found and these values were put into equations 3 and 4. The remaining terms were then altered to ensure that equation 3 was equal to or greater than equation 4.

Initially it was thought that there might be some problems with grip strengths that were too low to avoid slip on the closure surface. This lower limit was found to be 210N and it was found that this was not a problem as all consumers measured were able to apply grip forces greater than this.

However, equations 3 and 4 suggest that the torque required to open the closure is a function of the grip. Further, the wall of this closure is deep, this means that the wall can be flexed and pressed against the glass thread after it has been applied to the closure. Figure 5b makes it easy to visualise this affect, with the consumers grip pressing the wall of the closure against the glass thread. This will increase the friction between the closure and the glass. It will also squash the liner material were it overhangs the sealing surface at the top of the closure. Therefore the terms N_A and N_T are interrelated. Further work is being undertaken to establish this link and will be published at a future date.

What this work demonstrates is that the actual torque to open a closure of this type is dependant on the grip of the person or thing used to open that closure. This has profound impact on capper/fillers as it means that measured opening torque is relative. It is hoped that with further studies and measurements, data can be provided to the industry that enables the ‘normalisation’ of this data to the target consumer whether that is an elderly lady or first time drinker.

CONCLUSIONS

In conclusion it can be said that:

1. There are excellent social and business motivators for industry to take up the engineering approach to inclusive design.
2. The current human strength research is indicative of trends but specific measurements need to be taken for specific packaging.
3. The engineering approach to implementing inclusive design outlined in this paper ensures that the largest possible percentage of a potential product user group will be able to access that product.
4. The key aspects of this engineering approach to inclusive design are:
   a. Deriving and equating the human element of opening the packaging and the structural element of opening the packaging
   b. Determination of values or ranges of values for the terms in the equation using experimental and/or numerical techniques.
   c. Optimising the terms in the equation for any given human grip strength value to give the lowest possible bottle opening torque.

   d. Testing the new design with respect to the other functions of the packaging such as seal integrity.

5. The current average torque to open this closure is 1.41Nm while the industry target is 0.68-1.36Nm for the slip torque. This means that the bottles are currently over the industry targets and that women over 80 form the data sample collected will not be able to open the closure although due to an incomplete study this may change.
6. All consumers have sufficient grip strength to avoid slip on the closure surface and open this closure.
7. It is possible to grip the closure too tightly and make it harder to open. This happens due to the flexibility of the closure wall. A grip over 306N will press the closure wall and the glass together, increasing the frictional forces resisting opening at the thread interface.
8. Measured opening torque for closures of this type is relative to the person or thing used to open the closure.

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FIGURES

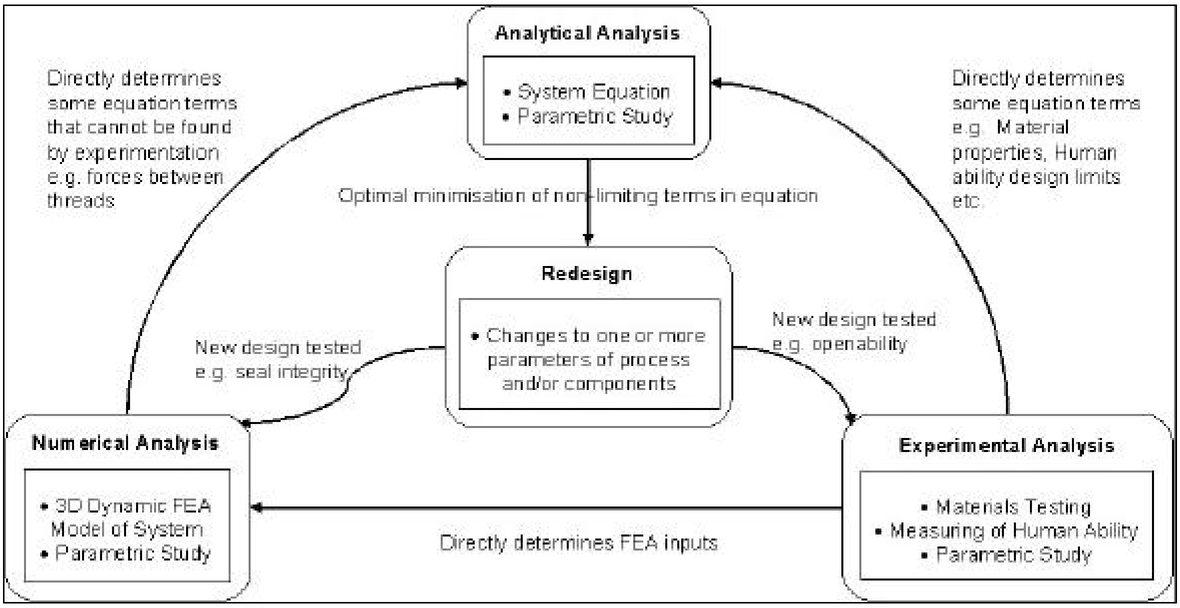

Figure 1: Showing the inclusive design methodology used to .ensure that the weakest target consumer can open the packaging.

Figure 2: Showing the ROPP closure before and after application respectively.

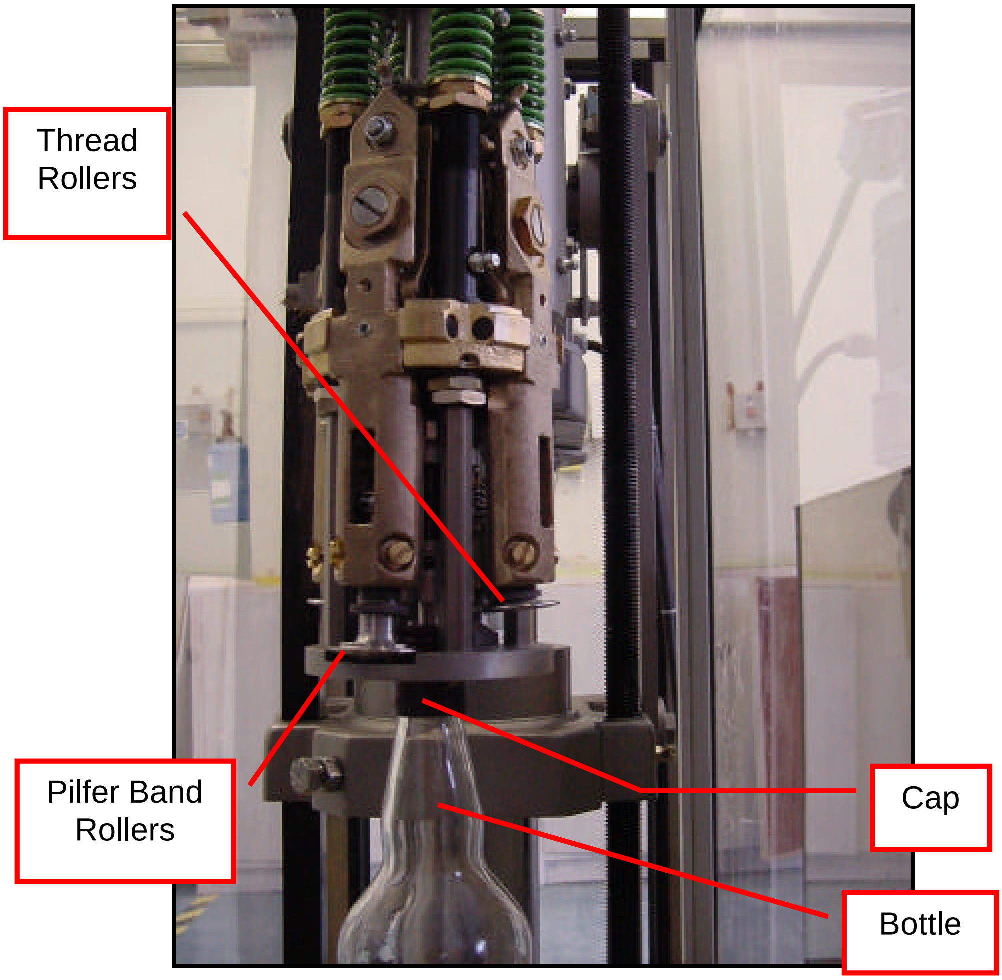

Figure 3: A single head capping machine used to roll thread and pilfer proof band into the closure.

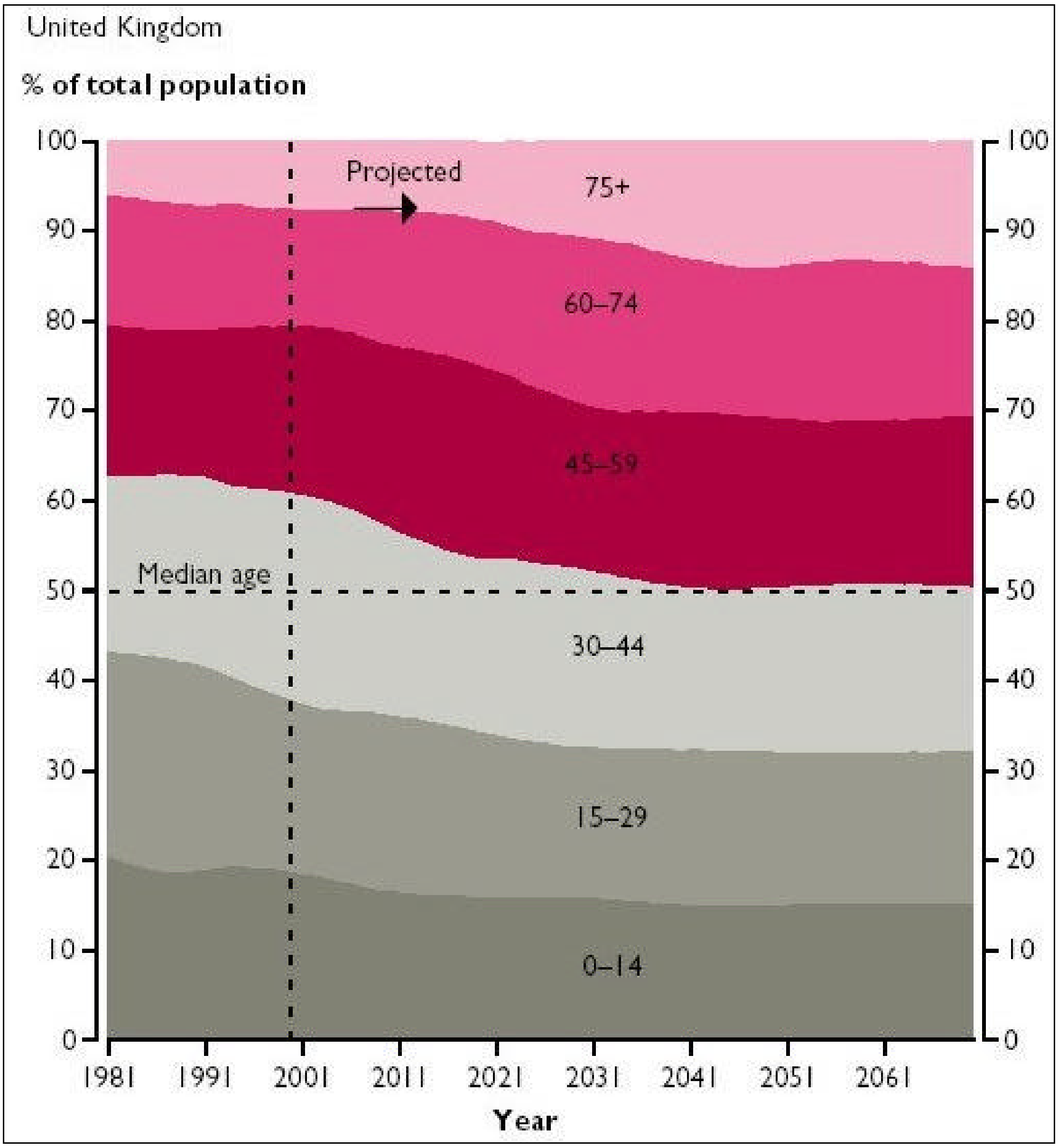

Figure 4: UK population predictions. (3)

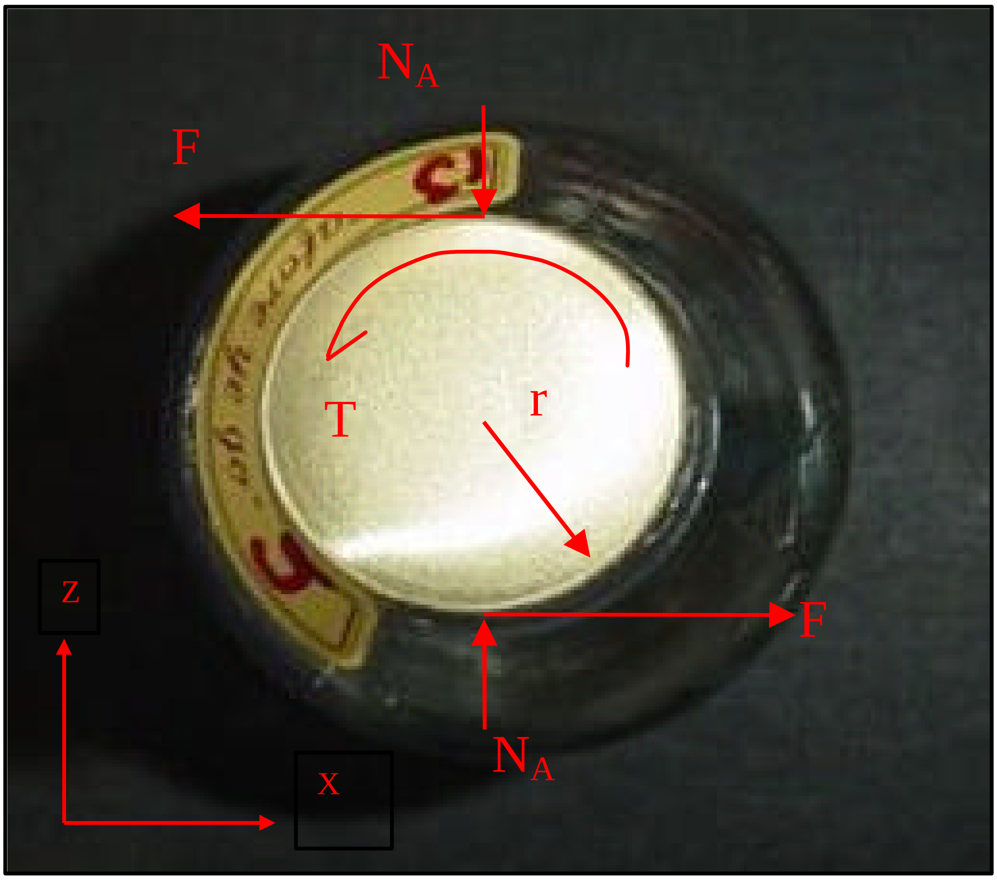

Figure 5a: A typical set of forces applied by a human to open an ROPP closure.

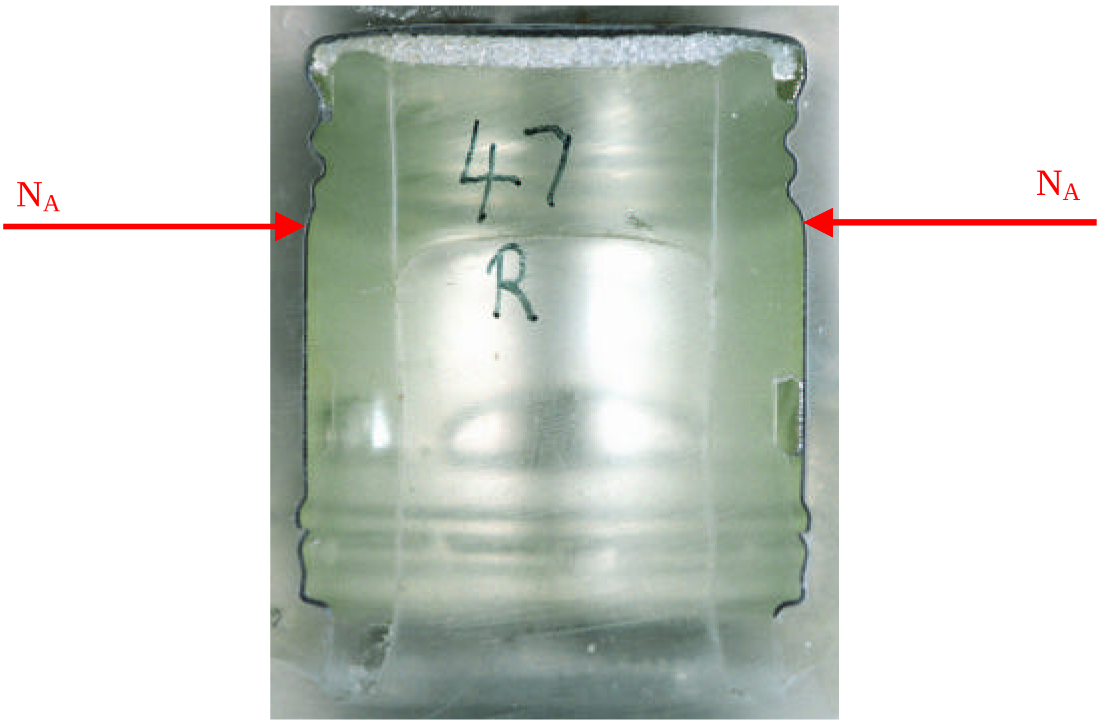

Figure 5b: A typical set of forces applied by a human to open an ROPP closure.

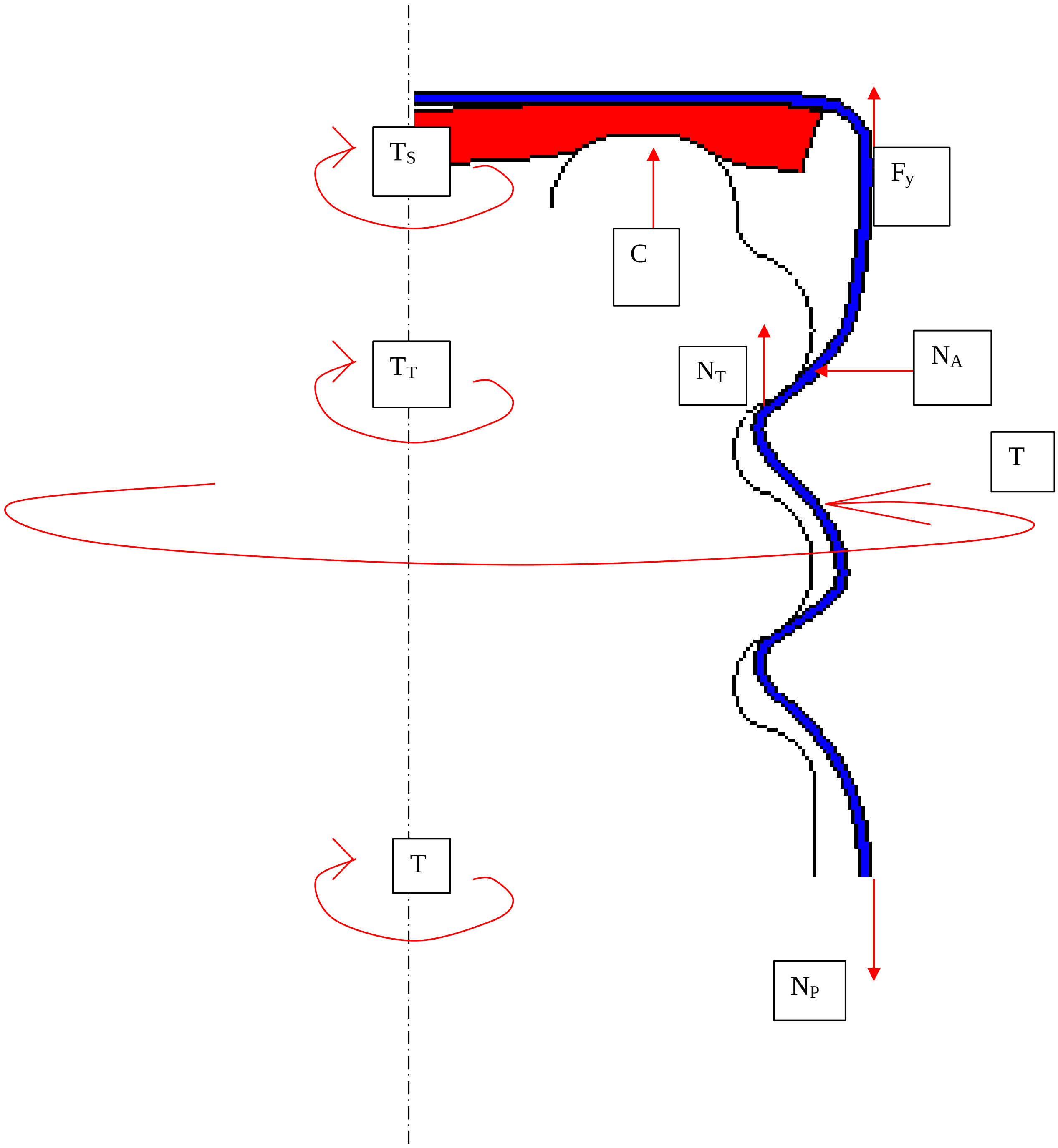

Figure 6: Part of the force diagram used to derive the equation describing the opening torque of the ROPP closure.

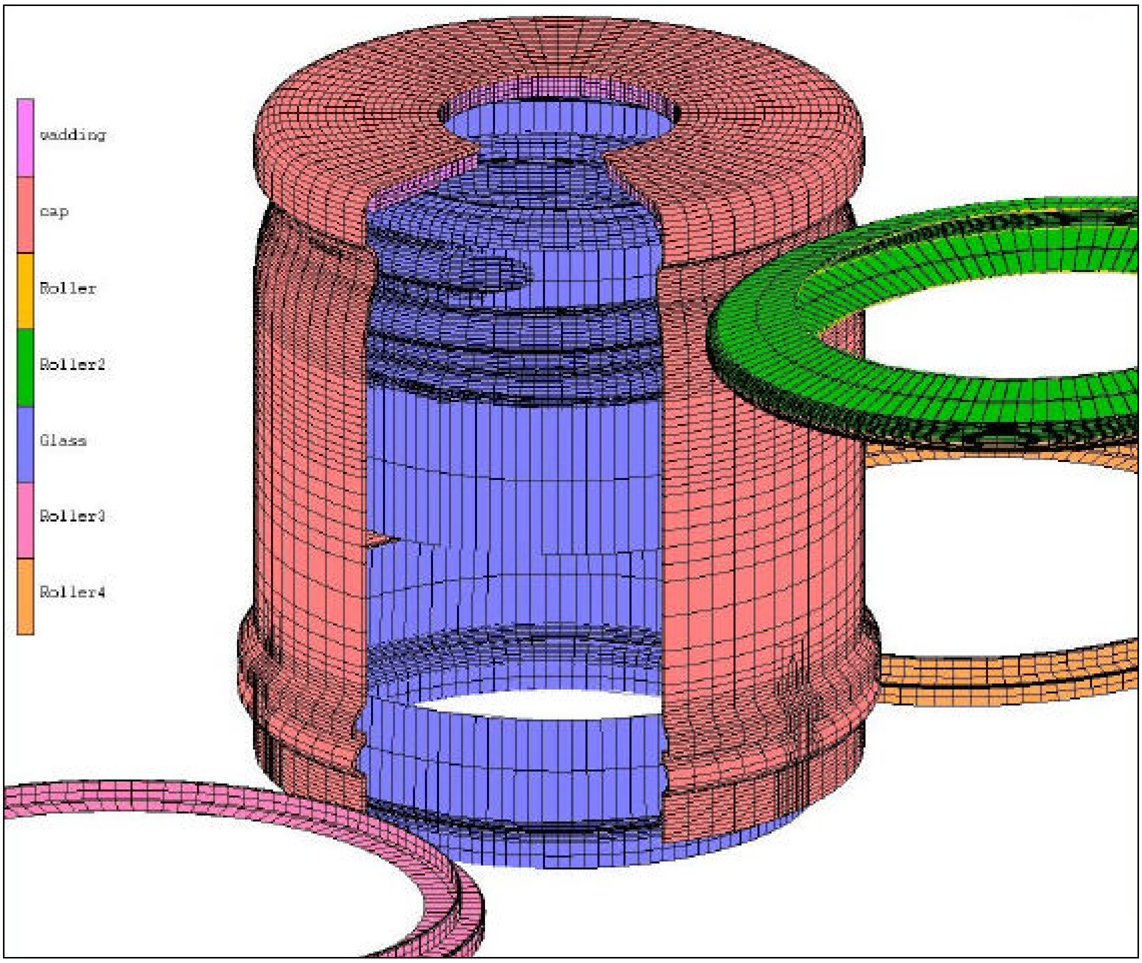

Figure 7: Schematic diagram of the FEA model created to analyse the capping process

Figure 8: Apparatus used to determine both friction co-efficient and flow stress of closure material respectively.

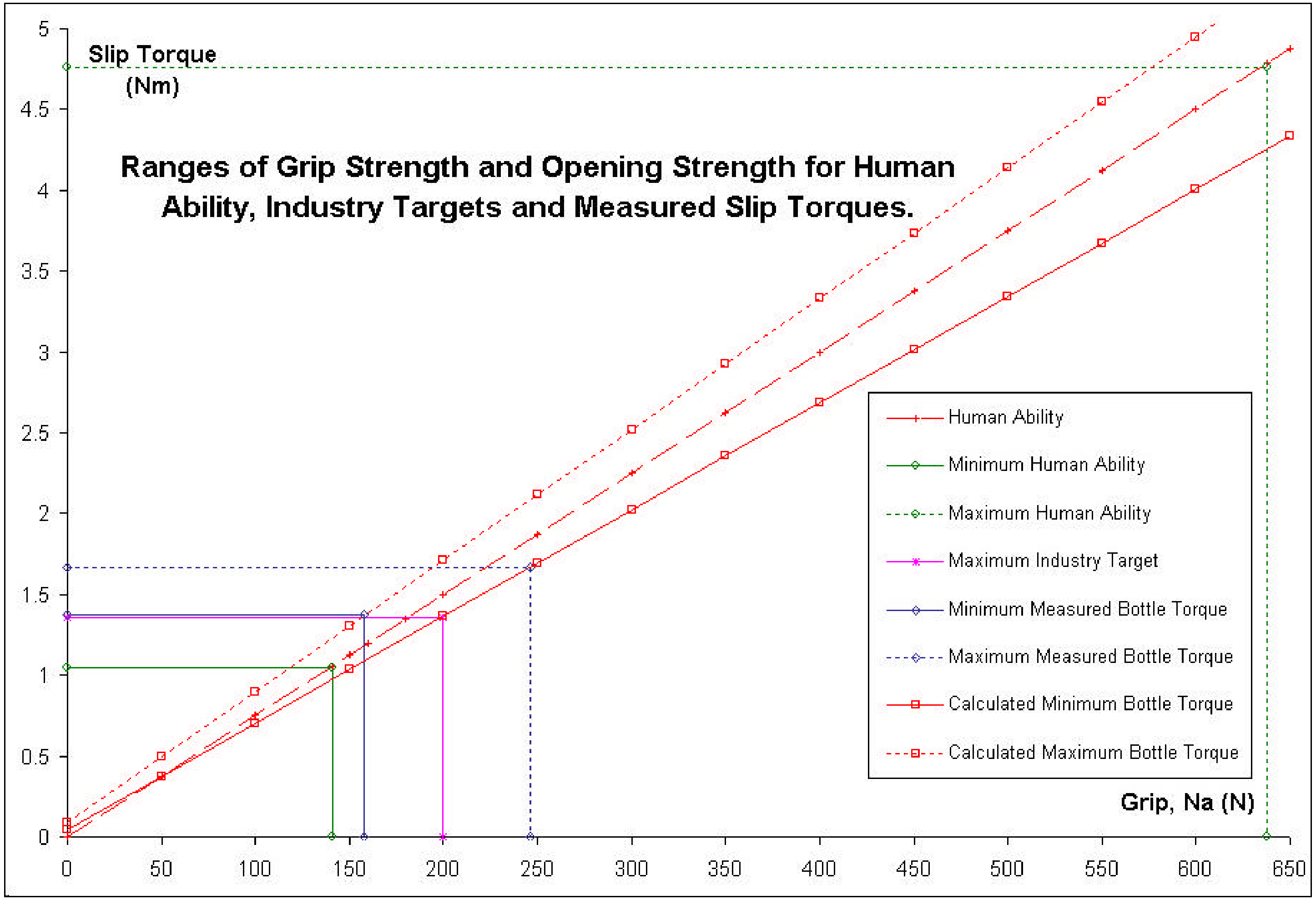

Figure 9: A graph illustrating the variations in human opening ability and the opening torque actually required to open an ROPP closure.

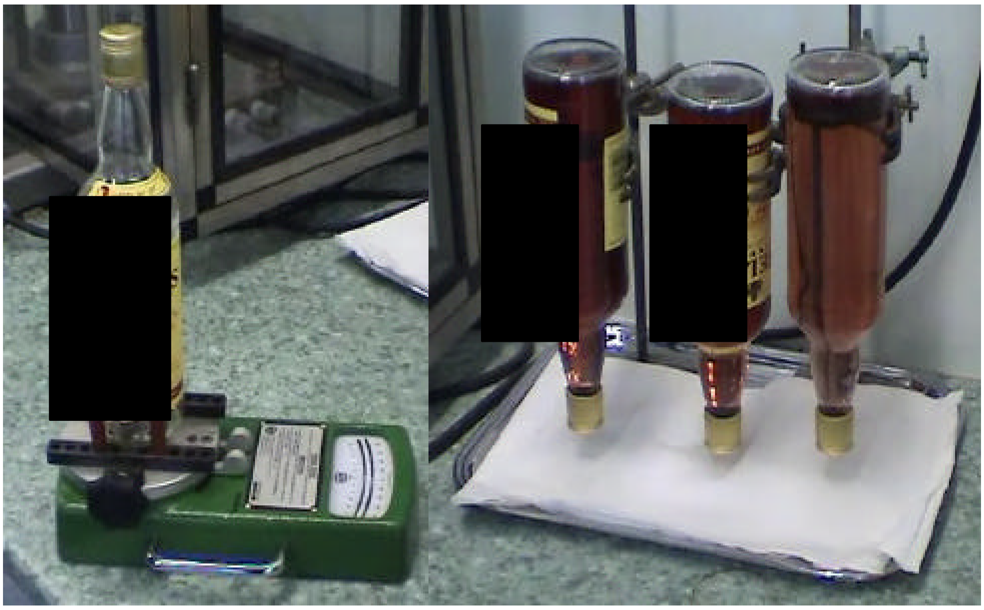

Figure 10: Testing openability and seal integrity respectively

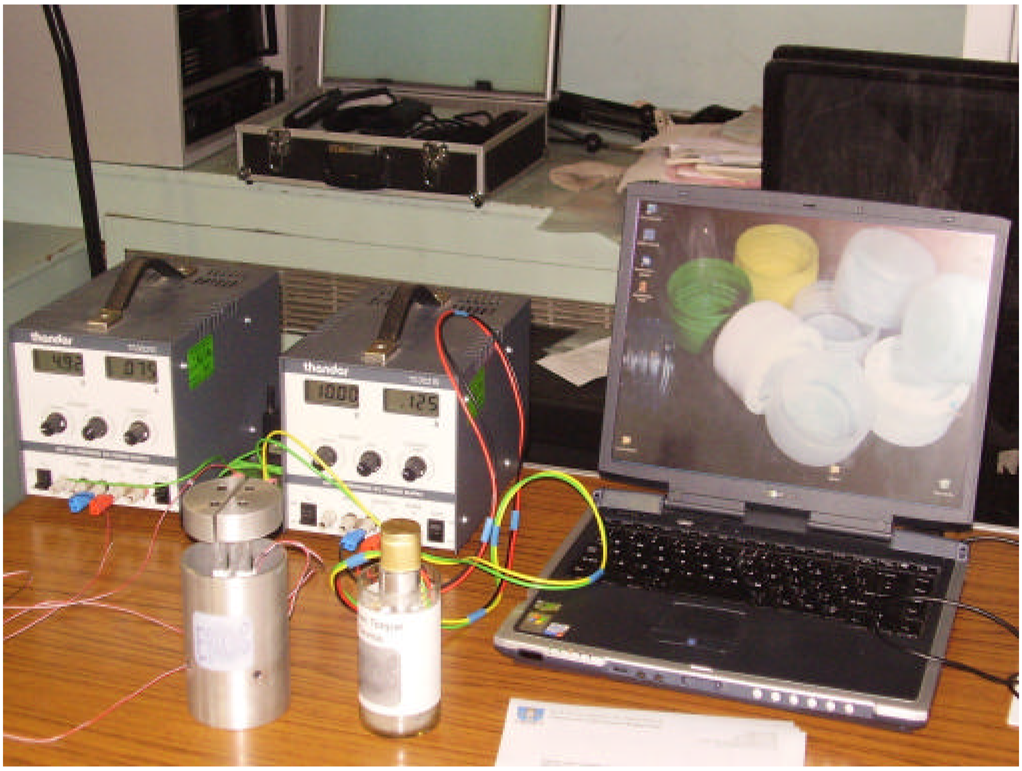

Figure 11: the instrument set-up for strength measuring showing the 2 power supplies between which is a pico sampler. The torque gauge is on the left (shown with a 30x35 extra deep ROPP closure on) and the grip gauge is on the right (shown with a 50mm diameter shallow closure on). These are approximately the weight of a full bottle and can be picked up and handled as the consumer feels most comfortable. The data is captured by the laptop.

Figure 12: the grip gauge with the 30x35 extra deep ROPP closure attachment on the left and an illustration of how it is used on the right.

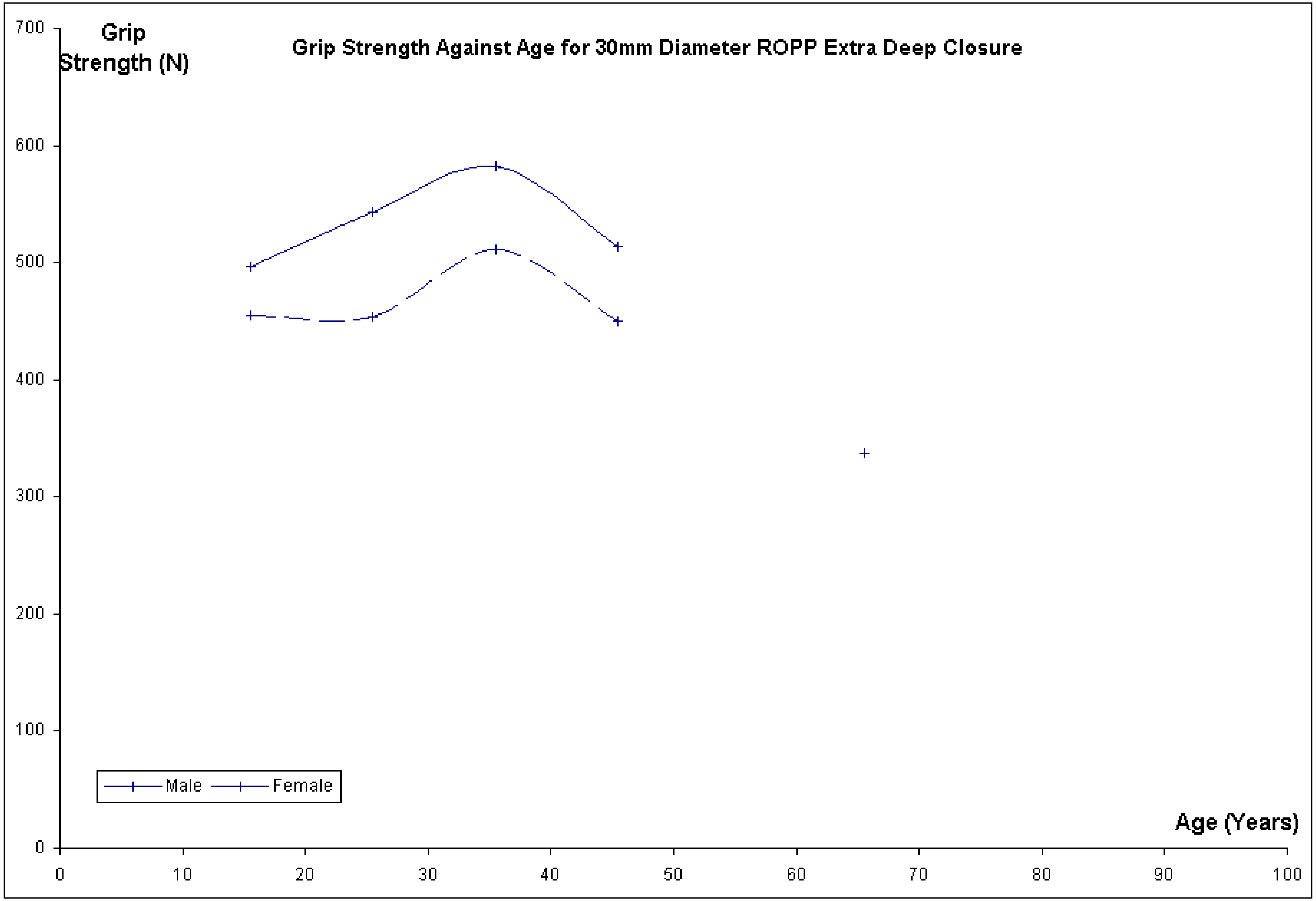

Figure 13: grip strength of men and women for 30mm diameter extra deep closure against age

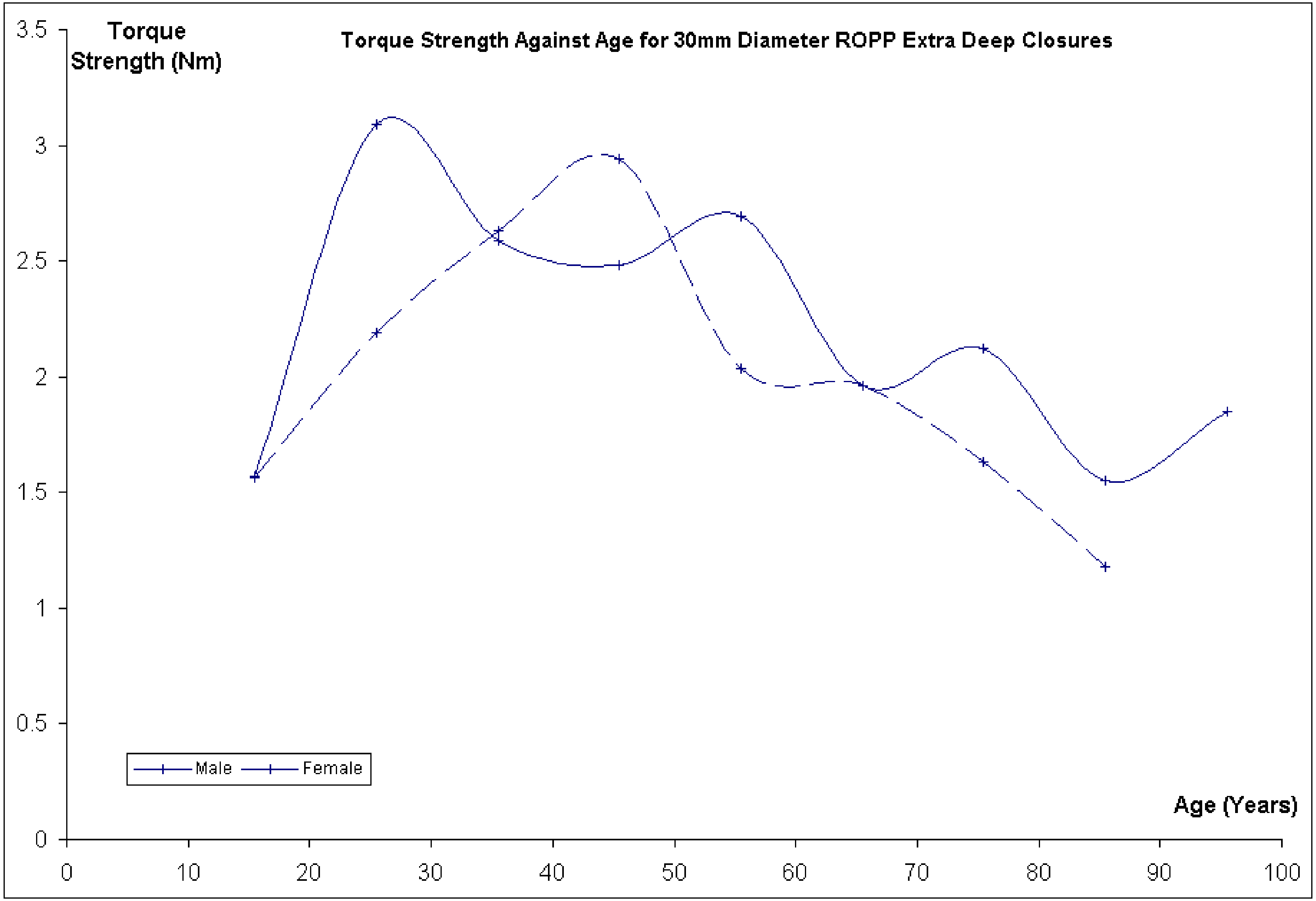

Figure 14: torque strength of men and women for 30mm diameter extra deep closure against age