Ball Design Construction and Manufacture

Introduction

How a ball reacts in a normal impact has been discussed (section “The Golf Ball and the Science of Impact”), and how it reacts to an oblique impact (Oblique Impact & Spin), as with a lofted iron. We now need to understand a little about how design and construction allows a ball not only to withstand the forces and amount of deformation involved, but also produces a variety of desired launch conditions in different golf shots.

It should be noted that all golf balls manufactured nowadays are ‘solid’ – that is they do not have the stretched elastic windings round a heavy core that was the basic construction for a hundred years or so. A solid ball made from a single lump of material was a manufacturers’ dream for a time in the belief that production would be simple and cheap, compared with the complexity of wound ball manufacture. However it turned out that the performance of such balls was generally unsatisfactory and that in any case their manufacture wasn’t as simple as had been hoped.

Instead we now have solid balls made in two, three, four or even five separate pieces (plus several layers of paint). Figures 1, 2 and 3 at the end of this section show three examples of one manufacturer’s ball construction; all leading manufacturers offer a similar range each with slightly different detailed formulations.

Various Parts of a Multi-layer Ball

All of these balls have a large central core and a thin cover – some thinner than others. That’s all there is to a two-piece ball. Three-piece balls have in addition a thin mantle between core and cover. (It’s called ‘boundary layer’ by some manufacturers – a very confusing terminology in view if its proper use in the air-flow round golf balls.) And finally four-piece balls may have an inner and outer core, or a single core and two mantles. We’ll return to these different parts but let us first look at the core.

The Core

The core gives the ball its basic resilience and strength. It is usually made from polybutadiene (PBD), an artificial rubber, but quite a few substances are added to the PBD to give the core the desired properties.

Zinc diacrylate – maybe around 20% – is added to increase the strength of the rubber. It takes part in a chemical reaction with the PBD molecules (called cross-linking) which links the molecules in the core together more strongly. Generally the more zinc diacrylate the harder the core. In manufacturing, the cross linking reaction is speeded up by heating or by adding small amounts of peroxide and zinc stearate. The latter also acts as a lubricant to make the cores easier to remove from the moulds during manufacture, making the manufacturing process easier.

Most of the pure rubber-like materials used in the core and other parts of the ball are not quite dense enough give an overall ball mass of 45.93 gm (1.62 oz) so zinc oxide or some other heavy filler is usually needed to bring the ball weight up to the maximum permitted. By selectively locating this filler as in the four-piece ball illustrated in Fig C the weight distribution of the ball, and so its moment of inertia, can be slightly altered. Increased moment of inertia can reduce the amount of spin imparted (and help retain it during flight).

Both effects are quite small.

Often other additives are included to colour the core for identification purposes, to ensure that the correct cover is put on the correct core where a range of balls are being manufactured and bins of cores are lying around the factory.

Despite the fact that these additives can amount to 30% of the core it is usual for manufacturers to describe the cores simply as ‘polybutadiene’.

Cover and Other Layers

Whereas most cores are made from polybutadiene rubber, with additives as noted above, the covers (and mantles) are made from one of two main groups of chemicals: ionomers, very often Surlyn, and polyurethane. Polyurethane tends to be softer than Surlyn, though there is a range of hardness for both materials. The use of different materials for the cover and mantle is mainly responsible for giving the ball the characteristics of being ‘soft’ or ‘hard’.

Hardness of golf ball covers can be measured by a durometer (shown left), an instrument that presses a small ‘bluntly’ pointed rod (an indenter) into the cover material.

The more force required to penetrate a given distance the harder the cover, the measure being on an arbitrary scale called Shore D. As you can see the hardness of the covers of the balls shown in Figures 1, 2 and 3 range from 39D to 70D and that just about represents the range in all golf balls.

While the core chiefly influences ball speed, the cover, and what it rests on, chiefly influences spin as well, of course, as durability. It is a bit more complicated than that but let’s just start from there.

Remember that a thick, hard, stiff cover will reduce the effective coefficient of friction. That will reduce the angle Amax for maximum spin and therefore mean that, compared with a thinner softer covered ball, shots with clubs of more loft than perhaps a seven iron will lose spin – at wedge loft a lot more spin. Of course it isn’t quite as simple as that. In multilayer balls performance of an outer layer can depend on the layer below.

In terms of performance, all manufacturers are trying to do five things (at least):

i. Get the maximum ball speed allowed by the initial velocity test at the driver speeds of fast swinging golfers.

ii. Get minimum spin with drivers for fast clubhead speeds.

iii. Get maximum spin with lofted irons.
iv. And with some of their models achieve aims (i) and (iii) above at lower swing speeds.

v. Get good durability

. . . . and do all these at minimum cost.

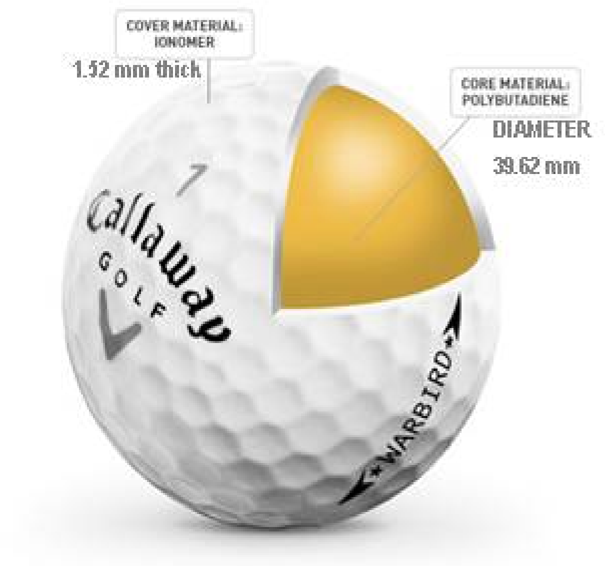


Figure 1 - A typical two-piece ball showing materials and dimensions. The cover is relatively thick and hard (about 70D). Many 'budget', 'value' or distance balls are like this. Picture produced with permission of Callaway Golf.

Figure 2 - A three-piece ball showing construction materials and dimensions. The cover is thinner and softer (about 60D) than that of the two-piece ball in Fig 1. Manufacturers whose top-of-the-range ball is three-piece have even softer and thinner cover – more like that of ball in Figure 3. Picture produced with permission of Callaway Golf.

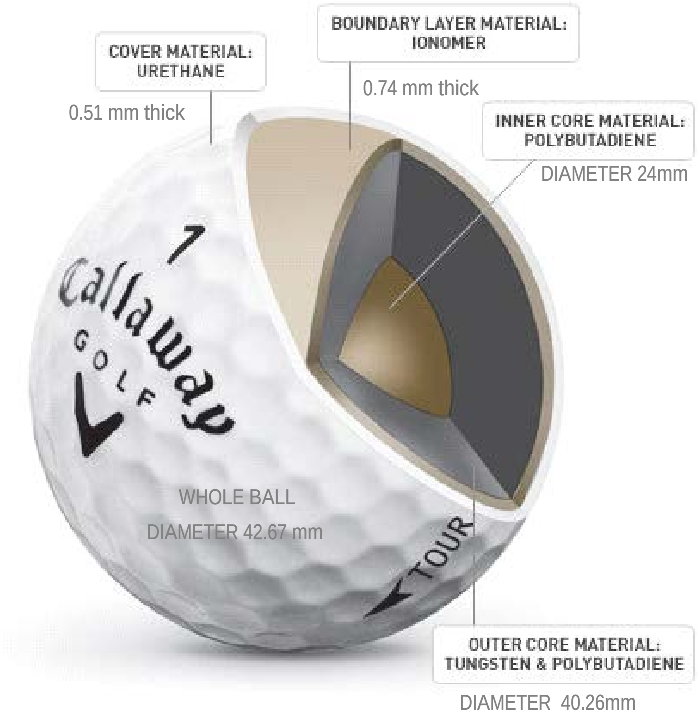


Figure 3 - A four-piece 'top-of-the-range' ball showing materials and dimensions. Other four-piece balls will have slightly different formulations and may have a larger core and two relatively thin boundary layers (or mantles). The cover in balls like this is usually very thin and soft (around 40D). Picture produced with permission of Callaway Golf.

The difficult-to-define quality of ‘feel’ is also thought to be important though good feel is somewhat subjective and in any case is probably achieved by a suitable combination of the other characteristics. In any event different sectors of the market put different priorities on these characteristics. Manufacturers have by trial and error, as well as increasing understanding of the process by which spin is imparted, come to realise that multilayer construction, with each layer having different properties can go some way towards achieving and prioritising these aims.

Pretty well all manufacturers say, or at least imply, that their particular ball, be it a tour ball or budget ball, achieves one or more of the above aims better than their competitors and they often explain this superiority in a kind of scientific terminology that ranges from plausible to meaningless. Beware of swallowing these claims too literally, though in fairness it should be said that they are often just an exaggeration of a small but genuine technological advance.

Without question it is true that variations in size, hardness/softness, density and resilience of the different parts of a multilayer ball can provide different playing characteristics. It is worth looking at the manufacturers’ websites – Callaway, Titleist, Srixon and others – and just weighing up what they say against what you now know about golf ball behaviour at impact.

The simple science will tell us that the recipe for a lot of spin is a thin compliant cover on top of a relatively stiff next layer. If we want to retain spin with lofted iron shots, but reduce it relatively with the much harder driver shots then we need some spin reducing mechanism deeper in the ball where compression in a drive reaches. The ball in Fig 3 claims to do this with its low compression inner core. Do you think that is plausible?

Cores can be made harder (deform less on impact) by adding more zinc diacrylate. In theory this should mean less energy loss on impact and greater ball speed. The same effect (less deformation) also occurs if the cover is relatively thick and stiff (Surlyn rather than urethane for example). These are characteristics of so-called ‘distance balls.

However in terms of ball speed we should remember that the manufacturer will be trying with every ball in his product range to get as close to the limit imposed by the R&A’s Initial Velocity Test. For this reason distance balls, if in fact they do go farther than softer balls are unlikely to do so because of higher speed off the clubface, but more likely because they spin less and therefore suffer less aerodynamic drag (and maybe launch a degree or two higher). Despite that you will still see some advertisements claiming unmatched speed from the clubface. If ball X leaves really the club face 2% faster than ball Y it’s likely to be illegal! (Or ball Y is a really duff ball!)

One area where additional ball speed may be achievable is in designing balls for slow swing speeds. The R&A Initial Velocity test effectively limits ball speeds for the fastest swinging golfers. There is no limitation at slower speeds. Multilayer construction probably does offer the opportunity to add a bit of ball speed on impact with a driver head travelling at 40 m/s (90 mph) without doing so for a 55m/s (123 mph) clubhead.

Remember also that it’s not just ball speed that determines drive distance. Reducing backspin and raising launch angle off a driver may be just as important and this is probably where multilayer balls have greatest effect in drive distance.

Effect of Temperature

Many material properties are sensitive to temperature change. Rubber-like polymers are no exception and can change quite dramatically at extremes of hot and cold. Over the range of temperatures in which the game is played things aren't so drastic, but the performance of golf balls is still slightly affected by differences in temperature.

The main effect is that as temperature decreases energy losses in the material increase – with a consequent reduction in ball speed. The effect is (or was) greatest in the now outdated wound balata covered balls, in which a temperatures drop from 40°C to freezing (0 °C) causes a decrease of about 10% in COR of the ball. In a hard hit drive that COR drop loses around 15 yards carry.

With modern solid balls the temperature effect is less and seems to depend on the hardness or softness both of the cover, and of the core and other layers, with softness reducing the effect of temperature change. The COR of most of today's multilayer balls changes by 2% to 4% over the temperature range we've been considering. That amounts to perhaps 3 to 6 yards in a hard hit drive and quite a bit less in the average golfer's drive.

Remember, however, that for most of a round the ball temperature will be close to the air temperature. The same 40°C drop in air temperature might lose a further 10 yards carry. When we add the effect of more clothes, stiffer muscles and little run on the ball it's not surprising to find as much as 40 or 50 yards difference in drive length between a cold winter day and a hot summer day.

Compression Rating

In the days of wound balls compression rating was considered by some to be an important characteristic of the ball, and manufacturers produced otherwise identical balls in two or three different 'compressions' usually 100, 90 and sometimes 80. These were arbitrary numbers based on how much force was needed to deform the ball by a given amount in a pretty well static test – 80 compression was softest.

The actual differences in ball performance were much less than the marketing arms of the ball companies had us believe – indeed the whole idea originated from manufacturers' inability to achieve consistency in the difficult process of winding the stretched elastic on to the central heavy core. In a supposedly uniform batch there would be a range of balls with different compressions. It was then a short step to sort the balls into two groups at a late stage in manufacture, call them compression 100 and 90, attribute different performance qualities and so make a marketing success out of a manufacturing failing!

At a later stage it's possible that balls were designed to have different compressions (80 compression would have been way off as an accidental outcome). Ball markings often showed the number 80, 90 or 100.

With the present solid balls compression rating is rarely referred to, manufacturers preferring terms like 'soft' or 'firm' feel.

Which Ball to Choose/Recommend?

Does all this knowledge we now have about how different ball construction can affect performance help us decide which ball to use or recommend?

Probably the best practical advice is to look at the websites where most manufacturers suggest which of their own ball types is suitable for a particular type of golfer. These recommendations are generalised (that is they don't give numerical details of ball speeds, spins etc) and exaggerated but, as mentioned earlier, usually have some technical basis. So we should tend to believe each manufacturers assessment of the relative performance of his own range of balls, although the disadvantage of a particular golfer using a 'wrong' ball in that range is probably going to be less than is suggested. By contrast we shouldn't pay much attention to one manufacturer's claims against another – not even when apparently 'backed up' by 'test evidence'. When we compare a number of very good golf ball brands, with not much to choose between them in reality, it is pretty easy to set up a test that will show one is 'better' than another.

The reality is that, while mid to high handicap golfers may just be able to distinguish between extremes – a two-piece ball with thick hard cover compared with a soft feel three- or four-piece tour ball – most cannot tell the difference between other ball types, or ball brands, though they often think they can!

Recent tests on ball types using a robot suggest that in clean dry conditions a 'premium' ball (three or four piece, thin cover, soft feel etc) takes on more spin than a 'budget' ball (two-piece, hard, thick Surlyn cover) – sometimes considerably more – but only with very lofted clubs. At lower lofts these two extremes on the ball spectrum perform almost identically – not only in spin but in ball speed. The tests also suggest that on less than full shots – say a 40 yard pitch – the premium ball's spin advantage extends to slightly less lofted clubs.

Overall, therefore, translated to the golf course these tests show the premium ball gives some advantage within 100 yards of the green, but for all other aspects of the game there is nothing to choose between them (except the price!).

Remember however that the modern premium ball represents considerable design progress compared with the corresponding balls a few years ago. The modern ball retains the high spin at high lofts of the older ball, but spins much less at low (driver) lofts – in fact can get close to the optimum spin rate, depending on exactly how it is hit. Previous premium balls e.g. balata balls were deficient in speed and retained too much spin with the driver.

For many high handicap golfers, the hard-headed objective advice is to choose their manufacturer by whatever prejudice or pre-conceived idea they may have then buy the hard cover two-piece model of that manufacturer. They may then hit their drives a little further, with less slice and they probably don't need to worry about losing spin on wedge shots. Added to that it will be the least expensive ball in that manufacturer's range!

If that sounds too cynical then, as stated above, consult the website of the manufacturer of choice. Remember too that if a golfer believes he will hit further or straighter or with more control with a particular ball, there's a possibility he will do so, at least for a time.

Ball Manufacture

We have seen how the materials and construction of multi-layer golf balls affect their performance and move on to look at their manufacture – how the various pieces are made and put together.

A main requirement of the manufacturing process is to achieve the required ball geometry. Golf balls need to be as near perfectly round as possible. That requirement together with the need to use the mix of materials that will give them the desired performance limits the ways in which balls can be manufactured economically and consistently.

The Core

The first stage is to make the polybutadiene (PBD) based core. Like any rubber once PBD has been produced it cannot be re-melted so it cannot be 'injection moulded' (this is explained later). It has to be 'compression moulded'. The chemicals needed to form the core are mixed, then, with a consistency like that of clay or plasticine, the mixture is shaped into long sausage-like cylinders which are chopped into slugs (or 'blanks') with just the right amount of material to form the core.

The slugs are heated to their 'softening' temperature and placed in hemispherical moulds in a large heated plate. A similar plate is then pressed down on them forcing the rubber to flow into a spherical shape (see figure 4). This manufacturing method is called 'compression moulding'.

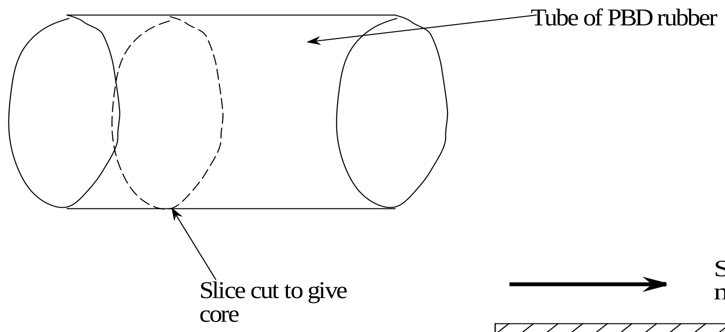


Figure 4(a)

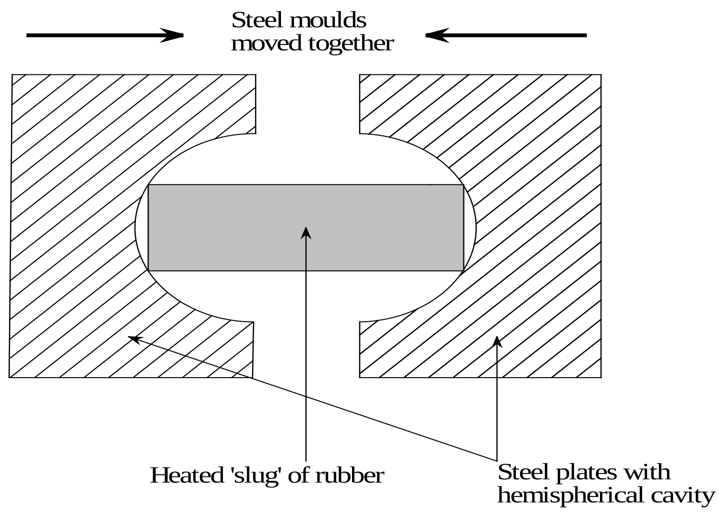


Figure 4(b)

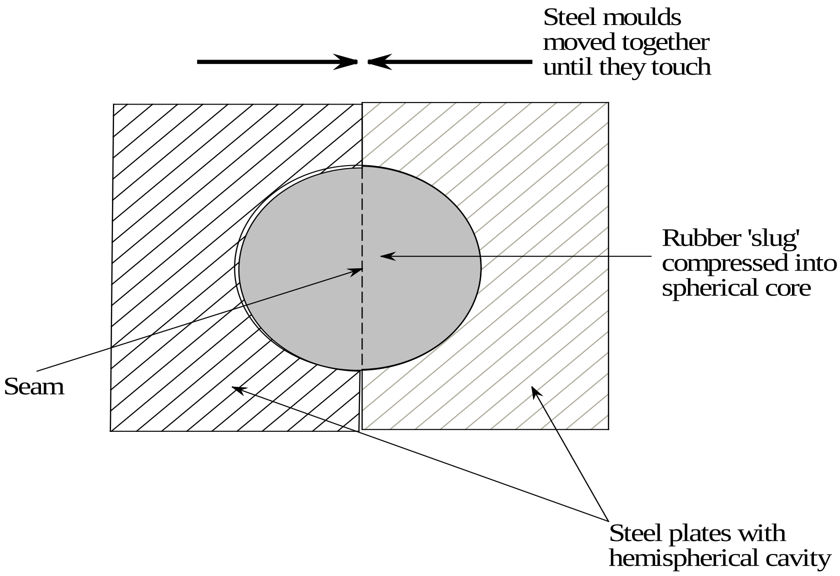


Figure 4(c)

Figure 4 (a, b & c) - Stages in compression moulding of a core; (a) correct amount of material is cut from tube; (b) 'slug' of rubber is heated and placed between shaped steel plates; and (c) plates brought together to force hot rubber into sphere shape.

Some of the rubber is squeezed into the joint between the two plates and leaves a ridge or seam on the core which has to be rubbed off. (See Figures 4c and 5)

Figure 5 - Compression moulded rubber core showing seam running vertically.

The cover

The cover of a two-piece ball can also be made in a similar way by first moulding two smooth hemispherical shells, then in a separate stage placing them round the core and compression moulding them into a single unit – an unpainted, unfinished golf ball. However compression moulding does not usually reproduce the dimple pattern well enough.

Fortunately the polyurethanes and ionomers from which covers are made can be re-melted so manufacturers can use 'injection moulding' a method also used for a lot of plastic components and items such as model kits. For injection moulding of golf ball covers the core is placed inside the spherical mould and held with retractable pins or low melting point polymers or waxes to give the correct separation. The inside surface of the mould has a 'negative' of the dimple pattern machined into it.

The mould halves are clamped together before any liquid polymer is injected. The polyurethane or ionomer is then melted, usually by a method known as friction heating as they are supplied as polymer granules, which when driven through a screw thread (known as a screw extruder) heat up and melt. The screw extruder also provides the high pressure that forces the liquid polymer into all the details of the mould – hence the better dimple reproduction than compression moulding.

The core supports, which keep the spacing between the core and the edge of the mould, melt or are withdrawn so as not to give holes through the cover. This does leave the solid core surrounded by liquid polymer and so some settling under gravity can occur to give a cover thickness that varies around the ball. This can result in the cover being thin on one side and thick on the opposite side.

Once the cover material has solidified and cooled the mould is opened and the ball ejected. The process is summarised in figure 6. The cover material will have a pigment added in order to colour the cover and make it more attractive; titanium dioxide is commonly used as a white pigment.

Figure 6(a)

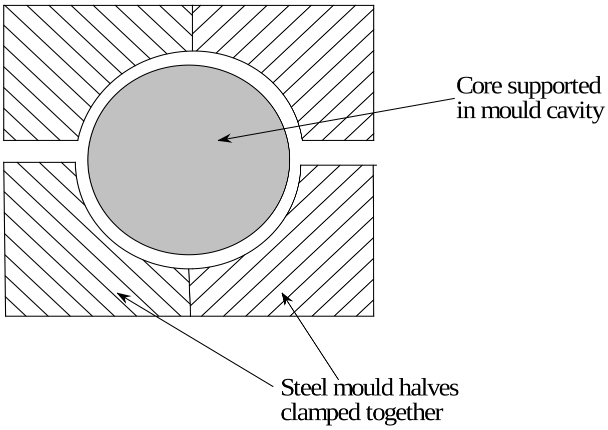
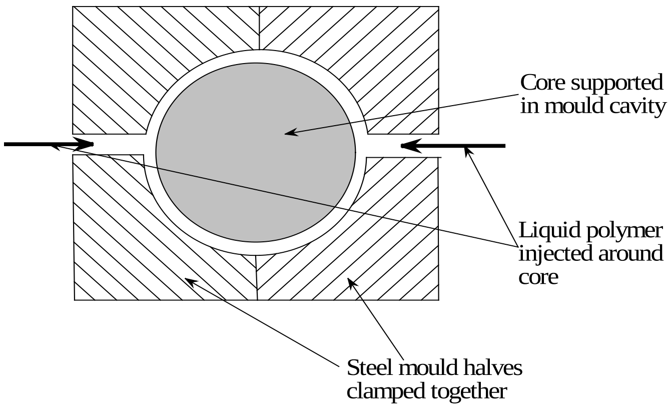


Figure 6(b)



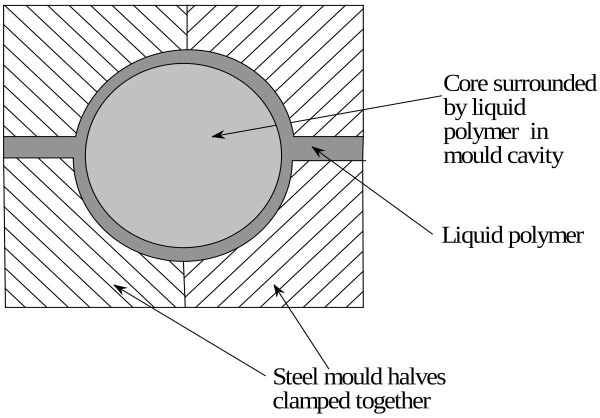


Figure 6(c)

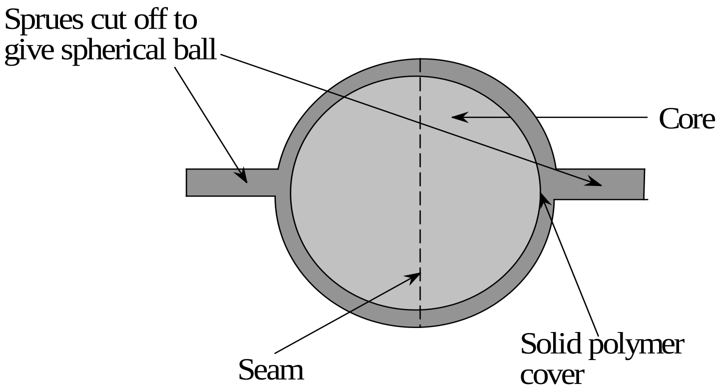


Figure 6(d)

Figure 6 - Schematic diagram of injection moulding of cover around a core; (a) core supported in mould and mould clamped; (b) injection of polymer; (c) liquid polymer filling cavity; and (d) polymer solidified and cooled, mould removed.

There is a seam along the joint line of the mould and the dimples have to be more widely separated here in order to be able to readily separate the mould halves and, more importantly, to extract the solid ball. This is visible on most balls as a line around the circumference where the raised ridges between dimples are wider, see figure 4 (below).

Figure 6(d) also shows the ‘sprues’, which are the solidified paths where the liquid polymer was injected. When cut or broken off they leave small pimples on the surface, which may or may not be polished off prior to lacquering depending on the manufacturer.

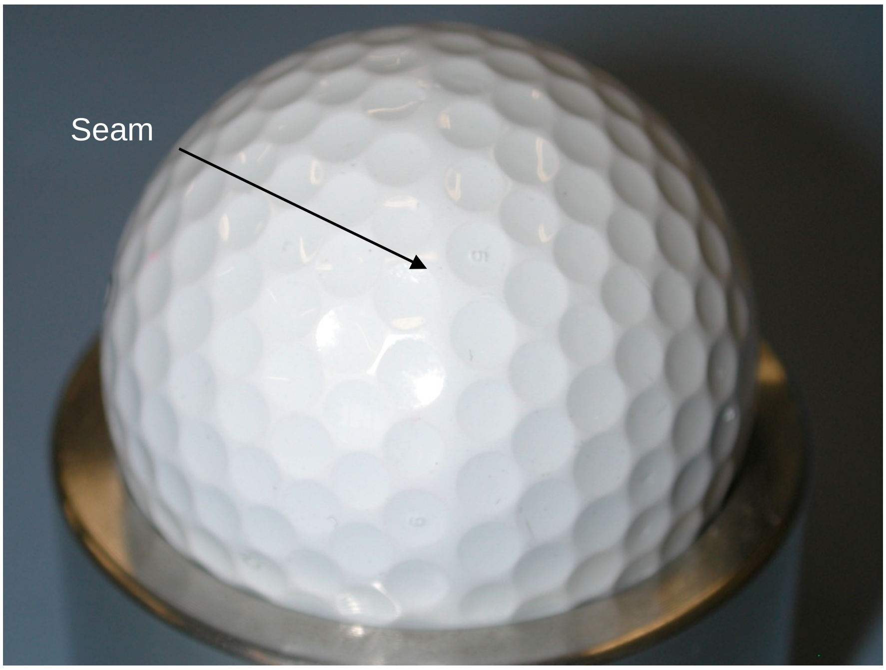


Figure 7 - Seam on a golf ball running vertically up the centre of the image and seen as a wider, continuous line of raised material not cut by any dimples; this was the meeting line of the two mould halves when the cover was injection moulded.

Manufacturing variability

Variations in manufacturing mean that no two balls are identical even in simple properties like size and weight, but improvements in manufacturing over the years have reduced this variability. One area that has also been improved, but still needs more is that of weight distribution and spherical symmetry. As we have seen injection moulding of a cover around a solid core can cause a variation in thickness around the ball, which, because the densities of cover and core are different, causes the centre of mass to move from the centre of the ball.

Non-central centre of mass will give a number of effects, namely:

The ball may not roll true on the putting green, tending to veer off towards the heavier side. In practice with most modern golf balls the effect is small. It may be noticeable if we roll it slowly across a snooker table, but is unlikely to be noticeable on even a very fast putting green.

As the heavier side of a ball will be harder (more cover material there) it will deform less on impact so may come off the club face a little faster. The difference between the two should again be virtually undetectable in play. The R&A’s symmetry test (no longer applied) does sometimes shows up small differences in trajectory when balls are set up differently on the tee, but these might also be caused by asymmetry in the dimple pattern.

Try this test to show that a ball may have a non-central centre of mass. Heat some water and add Epsom salts until no more will dissolve, i.e. the extra just sinks to the bottom of the container, cool it down and add a squirt of washing up liquid, then drop the ball into the solution. The washing up liquid allows the ball to move freely in the liquid.

Any non-central centre of mass will show up as the ball will float, like an iceberg, just breaking the surface with the same point (lighter side) always on top.

This off-centre behaviour is generally greater in two piece distance balls, where covers are thicker. The situation with a thick ionomer (denser than polybutadiene) cover is shown schematically in figure 8.

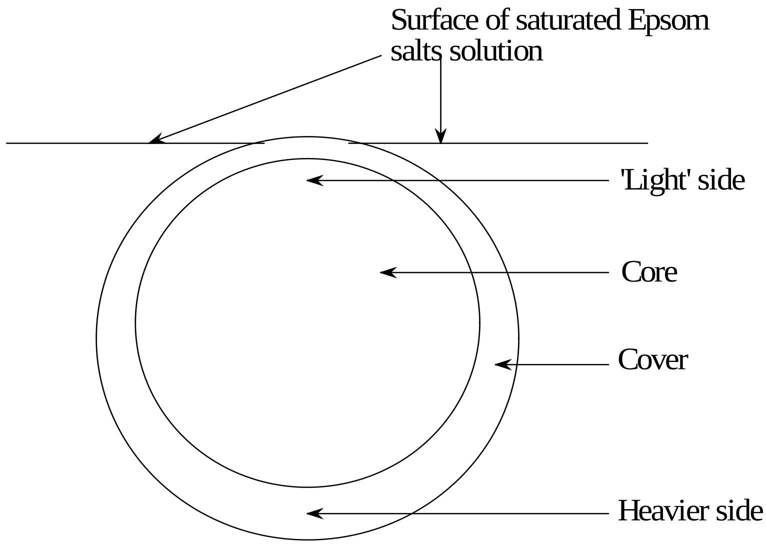


Figure 8 - Exaggerated cover thickness variation for a two piece ball.

Three-piece Balls

Three piece balls generally reduce this asymmetry by using a combination of compression and injection moulding for the mantle and or cover. The ionomer mantle is injection moulded as two constant thickness hemispherical shells separate from the core. These two halves of the mantle are then placed around the core and compression moulded at low temperatures so that they do not melt but just bond together at the join line. In this way the core is surrounded by a constant thickness of mantle and the centre of mass is at the centre of the sphere.

As with two-piece balls there may be some thickness variation when the polyurethane cover is injection moulded around the core and mantle, but the much thinner nature of the cover in three or four piece balls makes any effect from this small.

Finishing

"Flash" or rough spots and the seam on the moulded cover are removed. Two coats of paint are applied to the ball. Each ball sits on pins that spin so that the paint is applied uniformly by automatically controlled spray guns.

Next, the ball is stamped with the logo and finally a clear coat for high sheen and scuff resistance is applied. Throughout the finishing process rigorous inspection is carried out, often and most satisfactorily just by the eye of a human operator, to detect and reject balls with surface imperfections.