



CREDIT: STEVE LEE

Footwear Fundamentals

INJECTION MOULDING

Injection moulding has been described as a process by which a polymer is softened by heat before being injected into a mould, from which it is ejected once it has set to the shape of that mould. A huge proportion of today's footwear features injection-moulded components as part of their construction. They are made from a wide range of polymers and can be found as part of—if not the whole—upper, insole and sole. Far and away the most important application is of course for soling in the form of pre-moulded units or moulded direct onto the lasted upper.

There are two basic categories of injection mouldable materials that can be used for soling footwear: thermosets and thermoplastics. Thermoset materials consist of two products, VR (vulcanised rubber) and EVA (ethylene vinyl acetate). Thermoplastics, on the other hand, are a much bigger category and can be sub-divided into two distinct groups based on the final application. The first covers specialist products such as top pieces, plates for soccer, rugby and hockey boots, ski boot shells, ice-hockey boots and roller blades. The second and much larger group covers soling applications on everyday footwear. The polymers used here are generally PVC (polyvinyl chloride), PU (polyurethane), TPU (thermoplastic polyurethane) and TPR (thermoplastic rubber).

RUBBER

Injection mouldable rubber has been around for many years and is increasing its market penetration. The original

concept was to create a new type of powerful injection machine, where a thick ribbon of partially vulcanised rubber was injected into a mould heated to over 200°C. But there were some problems:

- Very robust machinery was required
- High mould temperatures
- Limited shelf life of the pre-vulcanised ribbon
- Cost
- Poor bond-ability of the rubber to other materials

These constraints were critical as there was a strong demand for dual component VR/PU soling for industrial boot applications. They were overcome by the development of rubber formulations with good bonding characteristics to PU, and by a machine head that injected a mass of spaghetti like strands of rubber into an open mould to produce an out-sole that was then compressed when the mould closed. Such an injection head could be fitted to existing PU moulding machines and integrated into existing processes. Machines of this type are now widely used throughout the industry.

EVA

EVA has also been in existence for many years but, initially, had to be produced in sheet form and components then cut and shaped to size. This created excessive waste, was time consuming and always left a porous cut edge. It was followed by a process which took a blank of partially cured EVA that was then further compressed to produce a



Injecting a ribbon of VR into the mould. CREDIT: DESMA

unit with a good surface finish. It was still wasteful and even more time consuming. Development of full injection moulding for EVA was complicated since it needed careful integration of precise machine control, special moulds and new EVA formulations.

The problem with the moulds is that non cross-linked EVA containing the blowing agent has to be injected into a heated mould, small enough not to allow any expansion. When the mould is subsequently cooled it must be opened quickly as total expansion from effectively full density down to 0.18 - 0.22 g/ml occurs as the sole unit springs out of the mould. It was very difficult to obtain consistent net fit sole and mid-sole units by this process. All the problems have since been resolved and there are now many such injection moulding machines available.

THERMOPLASTICS

The common link between the applications in the first thermoplastic soling category is one of hardness, since all of them require a stiff hard product generally over 90 Shore A for their different functions. This requirement is mostly met

by TPU or PEBAX (polyether-block co-polyamide polymers). The main processing conditions and constraints are similar to those seen for the softer TPUs used for general soling applications.

The bulk of thermoplastics used for sole units—whether PVC, TPU, PVC/TPU, PVC/Nitrile or TPR—are made as much softer grades in the range 50-60 Shore A. This softness helps to provide the flexibility, comfort and resistance to oils and chemicals required from the soling. All these materials have key requirements in common regarding their processing.

DRY MATERIAL

The first step in processing any thermoplastic material is to ensure it is moisture free. If this is not the case, any water present will be turned to steam during the injection process, leading to degradation of polymer systems as well as defects in the finished component. These show up as streaks or bubbles and give poor performance during actual use. PVC, TPU and TPR are all dried when produced and normally packaged in foil-lined bags or octabins. If exposed to the atmosphere, TPU will pick up moisture to an equilibrium level. At 50% RH, it will be in the range of 0.3—0.7%. If this happens, it must be dried in an oven or, preferably, a dessicant bed dryer with hot circulating dehumidified air at 60 to 90°C and a dew point of -30 to -40°C. The exact temperature and time needed will depend on the material hardness being treated (Table 1).

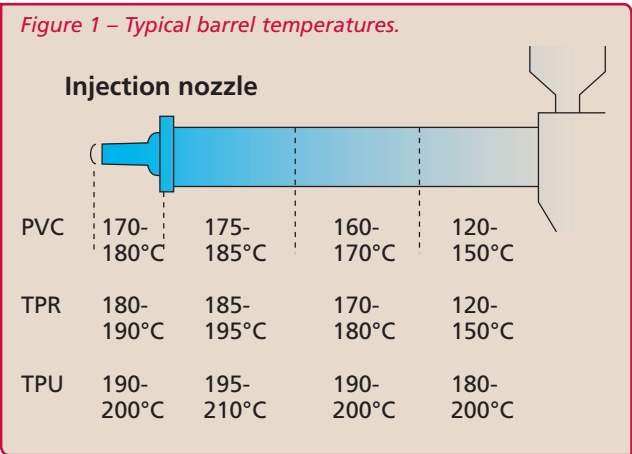
TABLE 1 – WATER CONTENT AND DRYING TIMES

Material	Water Content (%)	Drying Time (Hrs)
PVC	0.05 - 0.1	2 - 4
TPR	neg	N/A
TPU	0.3 - 0.5	4 - 8



A bank of EVA injection moulding machines.

CREDIT: MAIN GROUP



INJECTING POLYMERS

Simple ram machines can be used to inject PVC soles. However, far better results are obtained for PVC—and are mandatory for TPR and TPU—by using a pre-plastication screw model, fitted with a standard polyethylene screw with a length/diameter ratio of around 17:1 and a compression of between 2:1 and 2.5:1. Accurate temperature control is essential and typical barrel temperatures for the different materials are shown in the chart above (*Figure 1*).

Overheating can lead to polymer degradation and critical temperatures are 180°C for PVC, 200°C for TPR and 230°C for TPU. Insufficient heating, on the other hand, can also lead to degradation through local overheating caused by high shearing forces created by processing only partially melted material. Higher melt viscosity TPUs are especially prone to this.

Careful control of screw and injection speeds is a further key factor. Typical processing times for moulding a pair of men’s casual soles would be as shown in *Table 2*. With PVC and TPR, the units are easy to extract at these de-mould

TABLE 2 – TYPICAL PROCESSING TIMES				
Material	Inject	Hold	Cool	Total
PVC	5	5	40	50
TPR	5	5	45	55
TPU	10	5	55	70

times but are still elastic and easily marked. Surface details also tend to blur shortly after de-mould. Whilst TPU requires a slightly longer de-mould to ensure a good, non-deforming green strength, one of its major advantages is that it retains the surface finish of the mould (both matt and glossy) to an extremely high degree.

MOULD CHARACTERISTICS

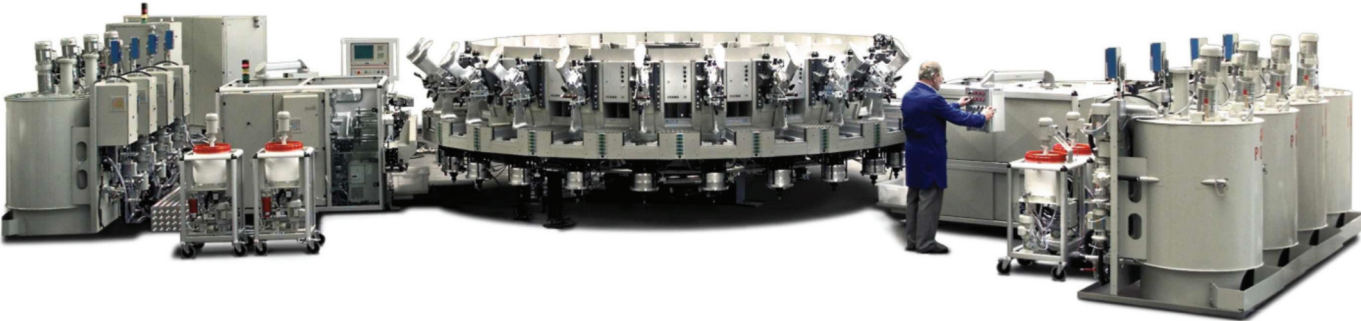
Moulds for traditional thermoplastic injection are usually made from steel, especially if intended for very long runs. For shorter runs, and when TPU is injected into an open mould, aluminium can be used. Whatever the material, all moulds need to be designed to avoid abrupt changes in the flow pattern of the molten polymer, as these can lead to surface imperfections. All corners and transition zones should have a radius rather than a sharp edge and pins and other obstructions that can lead to weld lines should also be avoided wherever possible.

Thick moulded sections are likely to cause sink marks due to non-uniform shrinkage as the component cools. These sink marks can be minimised by maintaining uniform cross-sections for ribs and reinforcing sections. Reducing the substance to 2–6mm greatly improves the situation for compact materials and also leads to significantly shorter de-mould times. Textured or matt-finished mould surfaces give the best results because they reduce the visibility of flow marks and provide for easier part ejection. Moulds for PVC are normally cooled with cold water, at approximately 10°C, whilst those for TPR and TPU are run at 20–30°C.

MOULD RUNNERS

Molten polymer is forced by the pressure of the injection screw through the outer gate of the mould and then into the actual mould cavity via a channel or series of channels known as runners. Large diameter fully-round runners are best and, although other designs such as half-round and trapezoidal can be used, they are not as efficient since they have a higher comparative surface area. Flat runners should be avoided as these can cause premature freezing of the melt, resulting in flow and sink marks.

Secondary runners should also be round, slightly smaller in diameter than the primary runner, and branch off at right angles. Flow should be as balanced as possible, so any



Rotary machines are used for direct injection PU . CREDIT: DESMA