



Integrated polyurethane footwear

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The main aim when designing footwear is to make the final product as attractive as possible to prospective purchasers. While vital, this is of course only part of the overall equation. In addition, a wealth of technical considerations have to be considered including grip, abrasion resistance, shock absorption, cushioning and ankle joint support, etc. In traditional shoe designs many visual and technical functions are performed by individual components such as for example a mid-sole made from blown polyurethane that combines low density with high shock absorption.

Similarly, various pre-cut and pre-fabricated parts help to complete all the other functions of the shoe. In most instances, these are assembled manually using processes involving either stitching or cementing in order to produce the finished shoe. Such traditionally designed shoes may contain as many as 65 distinct parts requiring up to 360 mainly manual processing steps for assembly. Producing footwear this way also has some distinct drawbacks.

CURRENT DRAWBACKS

Mass-producing footwear in this way requires numerous workers per production line with each processing step performed at a specifically equipped workplace. To achieve the required output, a number of identical workplaces for each processing step is often needed. As a result, production costs are mainly driven by increasingly rising

labour costs in shoe producing regions. In addition, manual assembly by cementing is becoming more and more restricted in terms of volatile organic compounds (VOCs) calling for new adhesives and processing procedures. And,

Figure 1 – A new approach to shoe design.



Figure 2: Inner frame on textile fabric in mould 1 (left) and out-sole pads in mould 2 (right).



Figure 3: Mid-sole (left) and complete shoe with upper in mould 2 (right).



finally, after-life recycling is in most cases not economically feasible since cemented shoes made from a variety of different materials are complex to separate.

Even though shoe assembly is predominantly manual, handling and processing of the individual shoe materials and components also requires machines and tools involving significant investment costs for shoe producers and their suppliers. For each new model, production and assembly lines may have to be specially configured prior to starting production.

In addition, short term changes in production schedules are often uneconomical. It can also take approximately eight weeks from order to delivery (standard shipping by sea container) for consumer markets in the US or Europe. Producers and retailers are therefore forced to estimate market demand at date of order and are unable to alter volumes and colours in response to changing demand.

FRESH APPROACH

Integrated design using polyurethanes could greatly simplify footwear production. Analysis of existing casual

footwear suggested that the required visual and technical functions can all be achieved using just four layers of polyurethane (Figure 1).

The shoe is broken down into four parts: inner frame, upper, mid-sole and out-sole. The inner frame is designed to bear high mechanical loads, stabilise the shoe and carry the lacing. The upper provides the desired visual design in terms of symmetry, colour and surface texture. In addition, it also needs to be flexible, geometrically stable and of low density. The mid-sole's function is mainly energy absorption and cushioning at low weight. Finally, the out-sole must be slip and abrasion resistant and, together with the mid-sole, also a visual element of the overall design. In the example shown, the out-sole has been reduced to simple pads placed in highly stressed regions of the sole.

THE PROCESS

All that is needed to produce such a shoe is one low pressure rotary table injection moulding machine and two mould sets per size for left and right feet. In the first stage, the shoe's inner frame is directly moulded onto a

carrier fabric pulled over a last (Figure 2 left). At the same time, the out-sole pads are produced in the second mould (Figure 2 right) and then the mid-sole directly onto it in the same mould (Figure 3 left).

The last with inner frame on its carrier fabric is then transferred into this second mold (soles remain in mould two). The upper layer is finally injected into the cavity between frame, carrier fabric and sole (Figure 3 right). This joins all four layers together without any cementing. The process is simply completed by de-moulding, flash trimming, inserting an insole and threading the laces.

An example of a finished shoe (Desma Quadwrap Trainer) is shown in the title image. It was produced using only three PU systems all developed and provided by Bayer MaterialScience.

INNER FRAME:	BAYTEC 89-430 (ADJUSTABLE SHORE HARDNESS A 65 TO A 90, HIGH STRENGTH)
UPPER AND MID-SOLE:	BAYFLEX 98-100 (ABRASION RESISTANT, GOOD FLOW, UV STABILISED)
SOLE-PADS:	BAYTEC CC 85-103 (EXCELLENT SLIP AND ABRASION RESISTANCE)

For each layer, properties such as shore hardness, colour or density can be adjusted in-process through variation of the component mixing ratio as well as the addition of colours or agents. These additives are dosed into the liquid polyurethane directly in the mixing head of the injection machine. The integrated additive dosing system can handle up to six additives or agents and, as a result of the self-cleaning function of the system, colour changes from shot to shot are also possible.

Using the same technology, a blowing agent can also be added with polyol, isocyanate, colour and blowing agent all homogeneously blended in the mixing head and injected into the mould cavity. Since mixing and injection takes only a few seconds, foam expansion practically starts in the mould. The expanding foam fills the cavity but keeps a closed skin at its outer surface. In the example shoe

shown, the addition of less than 7% blowing agent reduced upper/mid-sole density to approximately 220 grams/litre.

PRODUCTION

Production basically requires just one Desma D522 machine system (Figure 4). At the centre is the rotary table equipped with 24 or 36 mould stations moving counter clockwise. Two moulds per shoe adds up to four stations per pair and size resulting in six or nine pairs to be produced at a time on one machine. The four polyurethane layers are produced using two low pressure injectors and one micro casting head mounted to a six-axis robot. In addition, one robot sprays release agent into the open moulds while a second moves lasts between moulds one and two plus the manually operated lasting/de-lasting station. The entire machine can be operated by a single employee who also lasts the carrier fabric and de-lasts the moulded shoes.

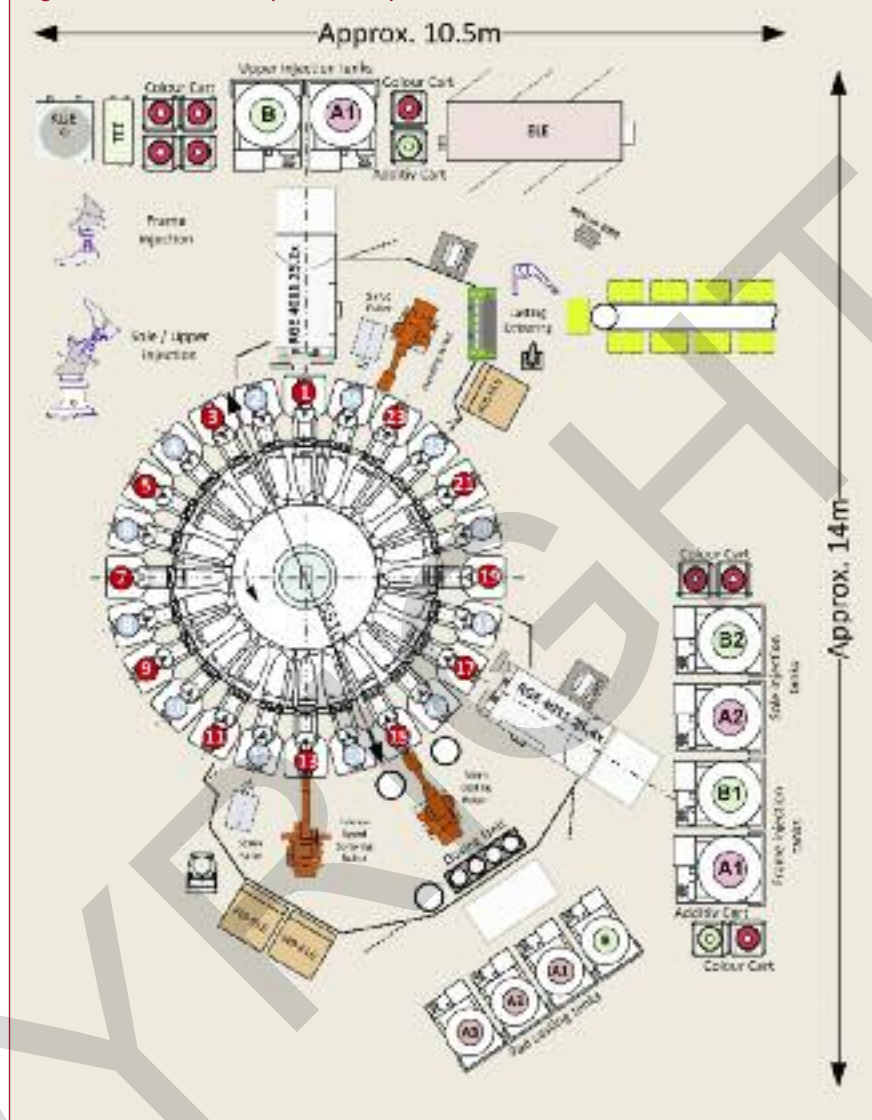
The cycle starts with manual force-lasting of the carrier fabric over a last and placing it in a transfer station. There, a handling robot inserts it into mould 1, the mould closes and the first polyurethane layer (inner frame) is injected. In parallel with this, the out-sole pads are cast into the bottom part of open mould 2. A dummy, replicating the lasted upper is moved in, the mould closed and the mid-sole injected.

After curing, sprue pulling and mould opening, the last—complete with inner frame etc.—is transferred from mould 1 to mould 2 by the handling robot. Mould 2 is closed and the fourth layer injected to complete the shoe. When this has cured, the mould opens and the handling robot moves the last with the finished shoe back into the transfer station for manual de-lasting. Two complete turns of the table are required to produce a shoe but, by parallel processing in both moulds, cycle times of well below 20 seconds are achieved.

ECONOMICS

A traditional manual shoe assembly line can employ up to 200 operators for an output of 1,200 pairs per eight hour shift. Manpower expenditure is therefore approximately 80 person minutes per pair.

Figure 4 – Machine concept and floor plan.



While material handling and, in particular, positioning of sub-components prior to assembly are predominantly performed manually, a significant number of production machines are needed for die-cutting and stitching uppers, lasting, injection moulding of sole units, cementing and then sole attaching. As a result, traditional production methods can create considerable investment costs particularly keeping in mind the fact that a significant proportion of the 200 operators involved will need specific machinery and tools.

As already explained, integrated footwear design and its automated production requires only one machine operated by one or two employees. Output from such a machine is estimated at between 330 pairs per eight hour shift with a 24 station machine and 560 pairs on a 36 station one. While this is considerably less

than achieved from a traditional assembly line, manpower expenditure per pair is reduced to approximately just three minutes, a more than 90% reduction compared to traditional processing.

Due to the high degree of process integration and automation plus the complex moulds involved, the investment cost for one direct moulding machine is likely to be higher than for a conventional production line. However, this will be more than compensated for by the greatly reduced manpower expenditure per pair that will be achieved.

POTENTIAL

Desma believes that this fully integrated system is capable of producing attractive and fully functional casual footwear. Due to polyurethane's great versatility, key properties such as high strength, low

density, slip and abrasion resistance are included, plus the ability to achieve almost any colour combination. In addition, both polyol and isocyanate system properties can be customised in-process by adjusting component mixing ratios and adding colours, blowing agents or other additives. Indeed, the addition of a blowing agent can reduce density anywhere down to < 225 gram/litre as required.

With this integrated design approach, shoe production can be simplified to polyurethane injection moulding and casting. All four layers are merged in-process by moulding mid-sole and upper directly onto a previously produced inner frame and out-sole. Cementing and, therefore, volatile organic compounds from adhesives are avoided. Making the shoe from just one material family is also a vital step towards cost-effective recycling.

On the business front, investment is simplified to just one injection moulding machine and there is total process control from raw materials to finished product. Footwear can be produced with a minimum of labour,

EFFICIENT PU

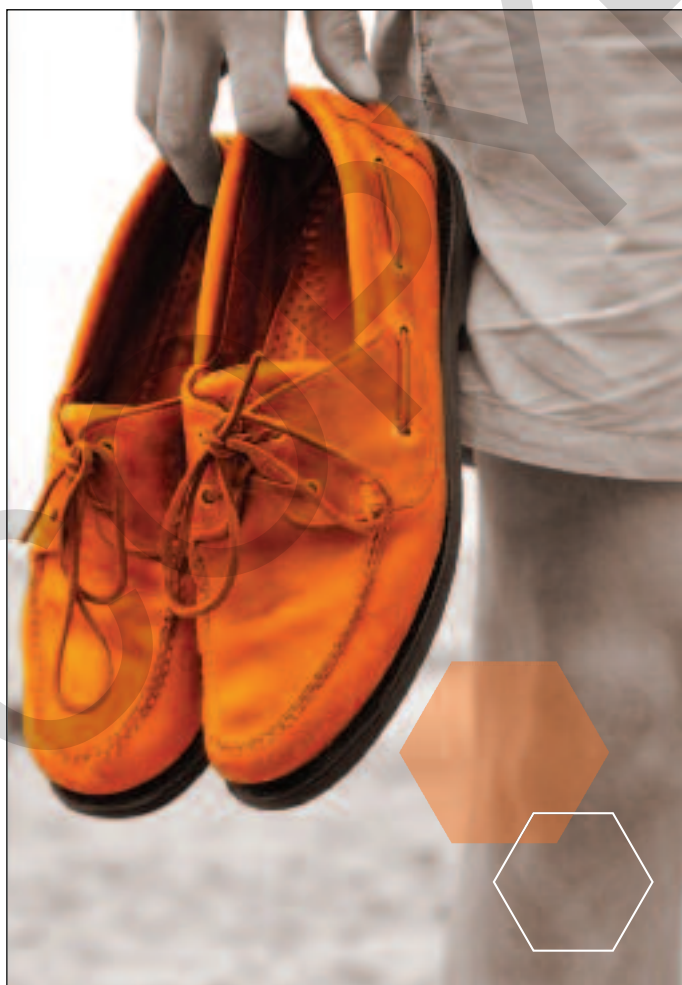
Polyurethane is an extremely versatile material and the Quadwrap Trainer demonstrates its potential for producing everyday footwear such as casual and athletic shoes. In footwear featuring midsoles, replacing traditionally used EVA for that component can also cut costs as well as simplify the overall manufacturing process.

In addition, PU offers superior material properties compared with EVA. Its high mechanical strength for example, makes shoes robust and durable. Not only are the Bayer PU systems used to produce the shoe particularly resistant to abrasion, tearing and tearing propagation, at 5–15% they have significantly lower compression sets than EVA (20–35%). In addition, thanks to their high flowability, they also offer greater design freedom than EVA in terms of fine detail and definition.

Because the individual PU systems also feature very low densities between 220 and 230 g/l, their potential for use in the production of lightweight sports shoes is comparable to that of EVA enabling manufacturers to produce a lightweight shoe at a competitive price.

energy consumption and resources. It also offers a totally practical option for those seeking to move footwear manufacturing back in-shore to high

labour cost countries and bring mass production closer to consumer markets with all the other advantages that brings. 



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