FOOTWEAR TECHNOLOGY: PU SOLING

Polyurethane has now been available as a soling material for over 40 years having first been introduced in the early 1970s. This was in fact a decade when three important new soling materials first appeared on the market; polyurethane (PU), thermoplastic rubber (TPR) and thermoplastic rubber (TPU). So how have these performed over the intervening years? Which are the winners, which the losers and why?

Where is PU as a soling material?

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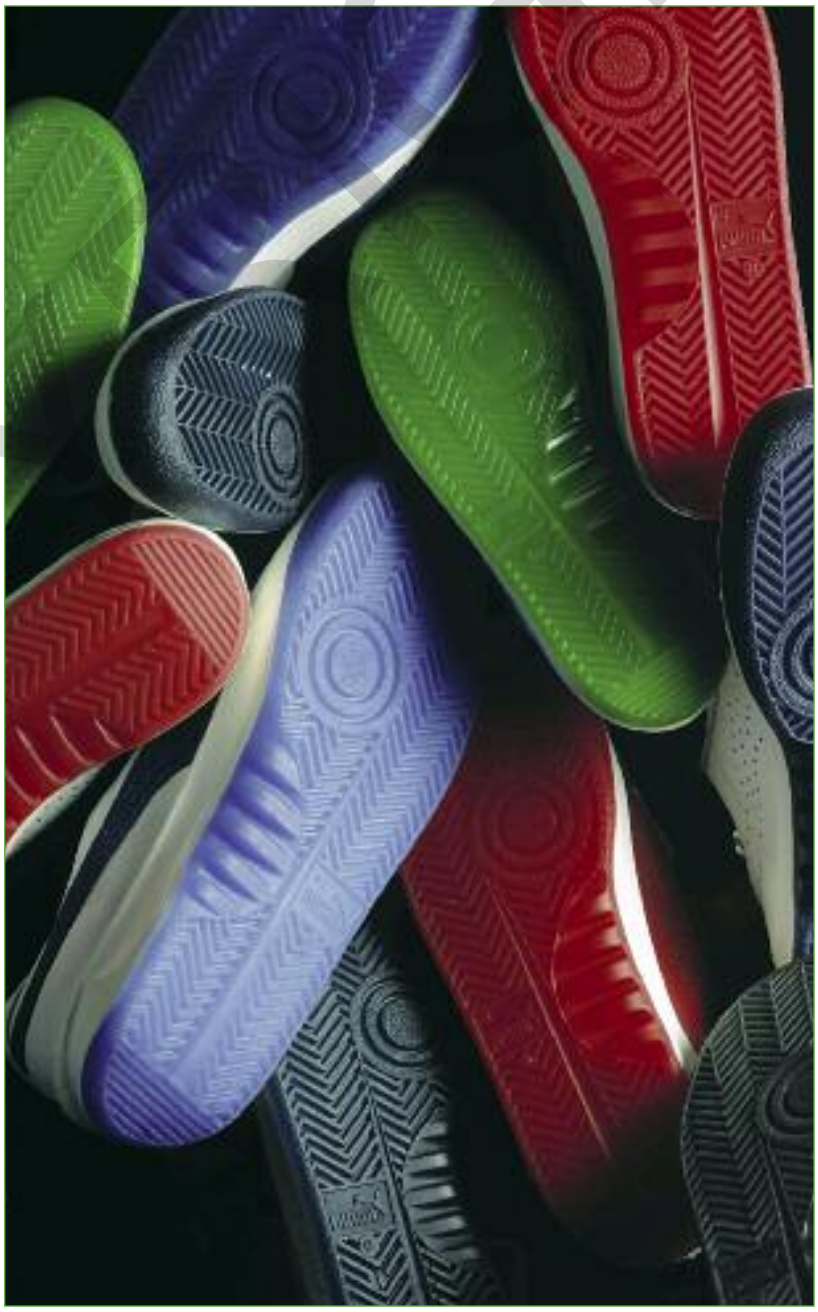

The world has changed dramatically in those 40 years, most noticeably in terms of population which has almost doubled from 3.8 to 7.1 billion. As the overwhelming majority of people wear shoes, it is no surprise that the production and consumption of footwear has also grown substantially. What is more surprising is that it had gone from 5.8 to 21.9 billion pairs or close to a fourfold increase, a growth in consumption per capita of over 101% from 1.53 to 3.08 pairs by 2012.

A wide choice

What is the range of materials that can be used for soling footwear and how have they changed over the years? There are in fact still only 11 different key soling materials and these have been brought into use over a considerable period of time *(Figure 1)*. However, as well as being used as single soling materials, they can also be used in a wide range of combinations such as VR/EVA, VR/PU, TPU/PU, PU/PU and TPR/TPR. Taking all these combinations, plus other more minor products into account, there are in fact well over 30 different soling combinations to choose from.

It is interesting to note that five of the primary materials form a related family in that they are all rubber-based; NR, VR, RR, TPR and LR. They nevertheless all have very different processing and performance characteristics, so where does PU fit in? One way of defining its position is to look at how these materials are fundamentally split by processing methods. When the market for total soling materials is broken down in this way *(Figure 2)*, it is clear that PU stands out on its own as does leather.

The fundamental difference with PU however

is that, unlike all the other soling materials, the final product is only formed when two or more components are combined in a special mixing machine and either poured or injected into a sole mould. With all the others, the finished product is already prepared and only shaped in the final process to create a sole.

The thermoplastic materials PVC, TPR, TPU, EVA and POE, plus others such as PEBAX and Nylon, dominate the soling market due to their ease of processing and the fact that most of them can be used on a variety of injection moulding equipment with no special machinery being necessary.

The next easiest materials to use are those that come in sheet form such as EVA, VR and RR which only need cutting and trimming to provide the finished sole. Typical products here are blocker units made from VR or simple EVA outsoles for flip-flops.

Then there are the pre-forms VR, NR and LR, where a portion of partially cured material is introduced to a mould and then shaped and cured by heat and pressure to produce the required sole unit. Everyone is aware that leather comes in the form of skins and hides, and needs shaping and trimming in a similar fashion to the sheet materials. Therefore it is quite clear that PU does indeed stand out from all the other soling materials used for footwear.

Market penetration

Has this uniqueness affected PU's penetration of the soling market since its introduction in the 1970s and, if so, how and why? The data in *Figure 3* shows that despite PU, TPU and TPR all being introduced at the same time, they now occupy significantly different positions in the soling market. TPU only has a relatively minor position at 174 Ktonnes and, whilst PU is better at 634 Ktonnes, it is nevertheless not even up to the level of leather at 644 Ktonnes. TPR on the other hand at 1,509 Ktonnes, has nearly two and half times the volume of PU.

Even if PU and TPU are combined they still only reach a total of 808 Ktonnes or about half TPR and less than EVA, a material that did not appear until the 1980s. More relevant still is the fact that PVC, introduced in the 1960s, is the dominant individual soling material with 2,839 Ktonnes and has overtaken VR at 2,443 Ktonnes. If the different rubber-based materials VR, RR and LR are combined, rubber and its derivatives taken as a whole still remain the major material source of soling material at 3,219 Ktonnes. So, despite being excellent soling materials, why have PU, TPU and TPR not performed better?

Figure 4 shows that all three materials have seen a steady growth in volume as might be expected with the ever increasing demand for footwear as the world's population has risen. The variations form a smooth curve and are to varying degrees the result of economic problems that have occurred during the past 20 years.

Logically, all three should also enjoy an increase in market share; only PU does. *Figure 5* shows that PU has increased its market share from some 4% in the early 1990s to around 6% by 2012, with half of that occurring in the last decade. TPU, despite doubling from 88 to 174 Ktonnes in the same period has shown no increase and has stayed constant at around 1.5%. The biggest surprise, however, is that TPR has actually lost market share, dropping from 15.2% in 1993 to a low of 14.1% in 2005 before recovering slightly to 14.3% by 2012 *(Figure 6)*.

Figure 1 – Introduction of different soling materials

1930	1940	1950	1960	1970	1980	1990	2000	2010
L	L	L	L	L	L	L	L	L
NR	NR	NR	NR	NR	NR	NR	NR	NR
	VR	VR	VR	VR	VR	VR	VR	VR
		RR	RR	RR	RR	RR	RR	RR
			PVC	PVC	PVC	PVC	PVC	PVC
				PU	PU	PU	PU	PU
				TPR	TPR	TPR	TPR	TPR
				TPU	TPU	TPU	TPU	TPU
					EVA	EVA	EVA	EVA
						LR	LR	LR
							POE	POE

Key:
L – leather, NR – natural rubber, VR – vulcanised rubber, RR – resin rubber, PVC – polyvinyl chloride, PU – polyurethane, TPR – thermoplastic rubber, TPU – thermoplastic polyurethane, EVA – ethylene vinyl acetate, LR – latex rubber, POE – polyolefin elastomer.

Figure 2 – Soling materials defined by processing

Processing	Products	KTonnes	%
Thermoplastic	PVC, TPR, TPU, EVA, POE, other	4,818	45.5
Sheet	EVA, VR, RR, other	2,064	19.7
Preforms	VR, NR, LR	2,398	22.8
Skins	L	644	6.0
Liquid 2-Component	PU	634	6.0
Total		10,558	100.0

Figure 3 – Soling materials consumption for 2012 (Ktonnes)

L	NR	VR	RR	PVC	PU	TPR	TPU	EVA	LR	POE	OTH	TOTAL
644	444	2,443	410	2,837	634	1,509	174	912	366	46	138	10,558

Problems for PU & TPU

We must therefore return to the question of why PU and TPU, despite a great deal of effort, have not made more impact on the soling market. The answer for TPU is fairly straightforward in that although it has the best overall properties of any of the soling materials and comes out highest in any perception analysis, it is also with the exception of some other 'specialist' products the highest cost material. It is only in the last 10 or so years that it has been possible to produce soft grades of TPU that can be blown consistently to a low enough density to even compete with PU let alone the other soling materials. So, for most soling applications, TPU is simply too expensive.

Although demand for it is growing, it is only for specialist niche applications. To make TPU a main stream soling material, radically new approaches need to be taken in order to reduce the cost whilst still maintaining the physical performance and, especially, the excellent processing characteristics. Of all the thermoplastics TPU provides the best surface definition and can mimic all sorts of surface finish from a mould, whether it be a matt or gloss finish, or fine detail definition.

The answer for PU is more difficult since it again provides soling materials with excellent performance properties. As the finished sole is produced in a mould using a reaction moulding machine then soles with a virtually infinite variety of density, hardness, colour, surface finish, physical properties, etc., can be produced by changing the formulation used. This makes PU the most versatile of all the soling materials and is why it can be found in all manufacturing segments other than ladies court shoes and certain types of sports footwear. So, once again, why has PU not been more successful as a soling material?

The complexity of the PU process is undoubtedly a major factor as also is the price of the raw materials used to produce the PU systems themselves. PU and TPU footwear products are based on three major raw materials, MDI (methy-lene di-phenyl di-isocyanate), a polyol and a chain extender. In the case of TPUs, these are mixed in a reaction extruder, usually with stabilisers and, if being blown, a blowing agent. The resulting compound is then extruded as clear pellets which can be sold to processors to create shoe soles with colour being added during the actual injection moulding stage. With PU, it is normal practice to produce two components, a prepolymer consisting of all the MDI and part of the polyol, and a resin containing the remainder of the polyol, the chain extender, catalysts, blowing agents (usually water) and cell stabilisers, plus any other specialist additives.

Figure 4 – Growth of TPR, PU and TPU 1993 to 2012

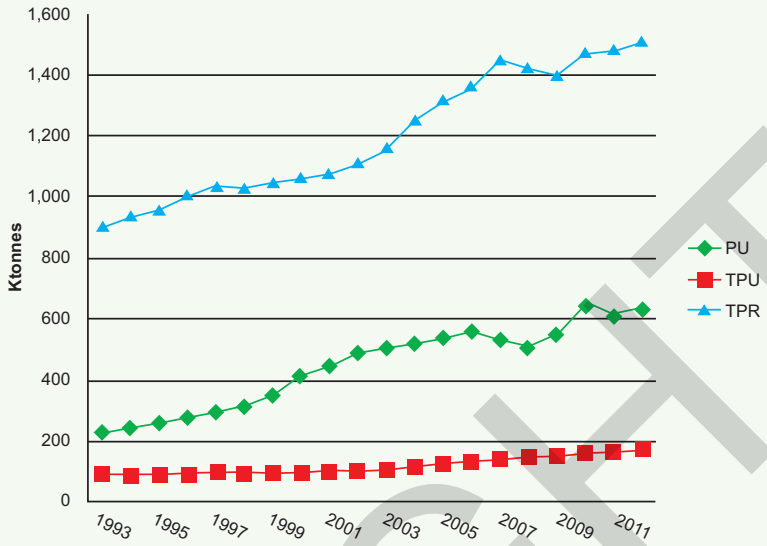

Figure 5 – Percentage share of the PU and TPU soling market

Figure 6 – TPR percentage share of soling market

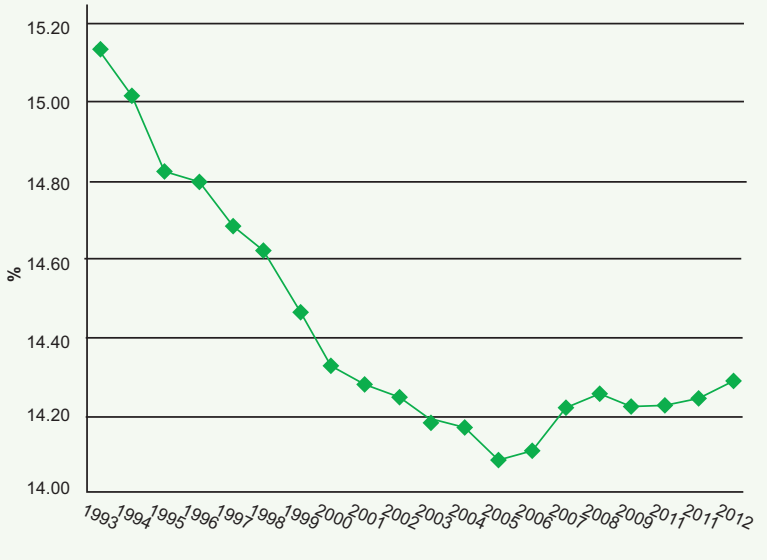

Figure 7 – Major users of PU soling (Ktonnes)

Country	1993	2012
China	13	302
Brazil	22	30
India	1	29
Italy	45	26
Turkey	5	24
Vietnam	0	20
S. Korea	20	14
Other	125	189
Total	231	634

Over 80% of both PU and TPU production is based on polyester polyols, with the remainder being polyether. Until now, polyester polyols have been predominantly based on adipic acid and a mix of diols, butane diol, ethylene glycol or di-ethylene glycol, often with a small amount of tri-methyl-propane to introduce cross linking. Similarly, the chain extenders are common and normally either butane diol or ethylene glycol.

In theory it is perfectly feasible to simply switch the type of soling material used for a particular type of footwear depending on price, style, availability, etc. In practice, this does not occur as readily as might be supposed. Most designers and brand owners tend to favour particular soling materials and to stick with them. It is only at the lower cost end of the market that choice is predominantly driven by the price of the soling material.

So, where is PU now?

Physically there has been a dramatic change over the past 20 years in where PU shoe soling is manufactured that has essentially followed the shift in footwear production from Europe and the Americas to being predominantly in Asia. Figure 7 clearly demonstrates this fact and shows that China now enjoys a very dominant position. So whatever happens in China will effectively determine the future of the PU soling market. If Chinese sole producers adopt new ideas, PU's share of the soling material market will grow; if they fail to do so, it will not.

One possible influence could be that of sustainability in the manufacture of PU polymers which was discussed in depth in *World Footwear* May/June 2013. Polyester polyol comprises up to around 60% of a PU or TPU formulation so if modifications can be made here, the effects could be far reaching. Various approaches have been explored including the use of waste CO_2 to reduceweight, carbon footprint and cost compared to existing oil-based polyols. An alternative approach is to adopt a bio-based route to producing a succinic acid which can then be converted into a polyester polyol using a mix of bio-based diols.

It is still early days but, nevertheless, it will be interesting to see just what opportunities may appear as systems developers learn how to incorporate these new renewable polyester polyols into their PU and TPU formulations. They have the potential to cause a major shift in the way PUF soling systems are produced if they led to lower-cost, improved processing and enhanced performance in wear. If this proves to be the case, PU could have a new lease of life and attain the global market share many think it deserves.