THE USE OF POLYURETHANE SPRAY FOAM IN STRUCTURALY INSULATED PANELS, (SIP's), AND COMPOSITE STRUCTURES

History
First produced by the German borne industrial chemist, Otto Bayer in 1937; today versions of polyurethane are ubiquitous and go largely unnoticed in many products throughout the world. Whilst early on these new compounds focused on the production of fibres and flexible foams; polyurethanes were used on a small scale as an aircraft coating during World War 2; with polyurethane became commercially available 1954 with evermore applications for this material having been discovered as the years progressed.

Benefits
Polyurethane foam is considered to be one of the most efficient insulating materials available, offering R-values of around 0.020. To put this into perspective, a brick wall of 860mm thickness would be needed in order to achieve a comparative level of insulation as could be achieved with only 25mm of polyurethane foam; with 45mm of mineral wool insulation, 140mm of softwood, and 380mm of concrete block similarly being required as equal alternatives.

Additionally, in the case of the closed-cell foam, when applied to facing materials, its ability to add strength to a structure gives it an additional appeal as a building material. Examples of this is the ability for the polyurethane foam to flow-through and adhere to the inside surfaces of a cavity, providing a continuous bond between material faces that can be used as a structural element with its ability to bond with the surfaces it comes into contact with. This can be demonstrated with its application to the underside of a roof, where it can help secure tiles and also offer a similar level of protection to that of a breather membrane; whilst also adding an insulting layer.

The adhesive bond strengths of polyurethane foams can be in the order of, or better than, $60Kn/^{m2}$. As well as its excellent insulating properties, this is one of the drivers for its use in the manufacture of structurally insulated panels.

Producing Polyurethane
Polyurethanes are in the class of compounds called Reaction Polymers, and are produced by mixing two or more isocyanates groups in the presence of a catalyst.

The properties of polyurethane can be influenced by the types of isocyanates and the polyols used to make them. These can range from tough or rigid versions, through to long, flexible segments; with different characteristics being controlled by the polyol using cross-links - the term given to a bond that links one polymer chain to another - with long chains and intermediate cross-linking making a polymer useful for making foam.

Types Polyurethane Spray Foam
Polyurethane spray foams are categorized as either 'open-cell' or 'closed-cell'; with several major differences between the two types, with both advantages and disadvantages for both depending on the desired application or requirements.

Closed-cell Polyurethane Spray Foam

The insulating gas that is retained within the cells of polyurethane spray foam when applied assists in achieving the excellent insulating properties this material has; placing it among the most efficient insulating materials currently available. In addition, the closed-cell nature of this foam provides for a highly effective air barrier, low moisture vapour permeability, (often referred to as the ‘Perm’ rating), together with excellent resistance to water.

The most common foam density for closed-cell polyurethane foam is approximately 32g/m^3. Closed-cell polyurethane foams can further be grouped by their rigidity and strength characteristics.

Principle advantages of closed-cell polyurethane spray foam can be summarized as:

- High R-Values of up to 0.020
- Has low vapour permeability
- Is highly effective as an air barrier
- Can increase wall strength when used as part of a composite structure
- Able to resist water
- The ability to absorb sound - Especially bass tones
- Medium density – typically around 32g/m^3

Open-cell Polyurethane Spray Foam

Open-cell polyurethane spray foam is usually found in densities ranging from 6.4kg/m^3 to 19kg/m^3. One of the advantages that these low densities provide is that they offer a more economical yield; since foam density is directly related to yield - lower density = higher yield.

Although the R-value of open-cell foams are only slightly more than half that of closed-cell foams, these products can still provide excellent thermal insulating and air barrier properties.

Open-cell Polyurethane spray foam is more permeable to moisture, with perm ratings of approximately 10.0 per 100mm thickness. However; the foam allows for a very controlled diffusion of moisture vapour whose consistency can be managed by correct specification.

Open-cell polyurethane foams are incredibly effective as a sound barrier too; having about twice the sound resistance in normal frequency ranges as closed-cell polyurethane foams. Other characteristics of open-cell polyurethane foam include a softer, ‘spongier’ appearance, as well as lower strength and rigidity than closed-cell foam. For this reason, these foams should not be relied upon to provide a structural element in the build environment. However, their other characteristics make them ideal for use in the manufacture of be-spoke structurally insulated panels.

Principle advantages of Open-cell Polyurethane Spray Foam:

- High R – values of up to 0.020
- Higher vapour permeability, but controlled
- Economical yield

- Effective air barrier properties
- Excellent sound absorption in normal noise frequency ranges
- Low density

Slow-rise and Quick-cure Polyurethane Spray Foams
Polyurethane spray foams are further categorized by their expansion rate and curing times once they are mixed and injected into a mould. These are known as either slow-rise or quick-cure.

For the production of be-spoke panels only slow-rise polyurethane foams should only be used; have a slower expansion rate and cure time than quick-cure types. This allows the foam to flow throughout the mould; filling the entire void *prior* to the foam curing. Quick-cure polyurethane foams, on the other hand, are primarily intended for open surface applications only; being able to bond to virtually any surface and cure in seconds; due, in part, to their limited flow time. For this reason they are used almost for applying to the underside of domestic roofs to provide an improved level of insulation to existing and older structures rather than using other insulation materials such as Rock Wool. The differences between using quick curing and slow-rise foams to manufacture a composite panels is clearly seen in figures 1 and 2.

Injecting slow-rise polyurethane spray foam into a pre-assembled panel is less time consuming and much cleaner than applying the quick-cure alternative onto an open surface. Slow-rise polyurethane foam also cuts down on wastage by reducing both the need for trimming and the mess from overspray commonly associated with quick-cure foams.

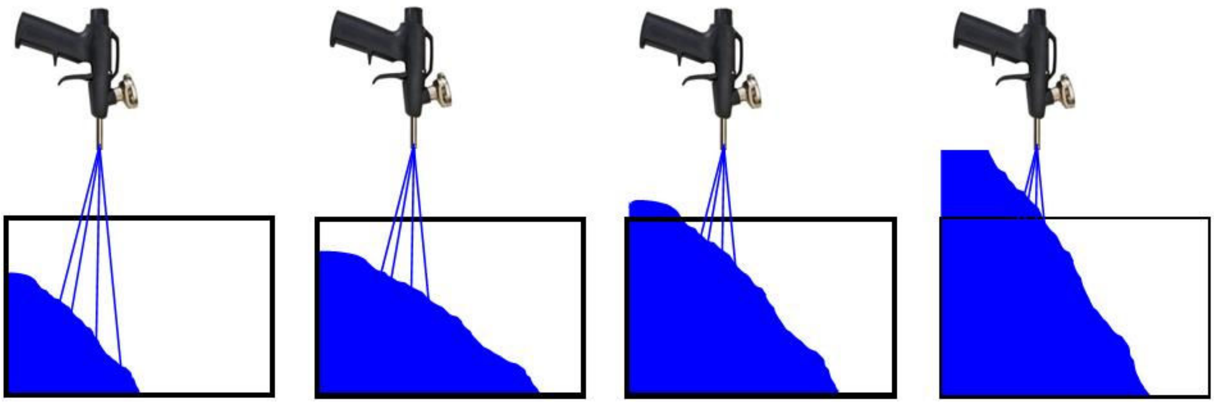

Fig. 1: The action of quick-cure polyurethane foam in a mould.

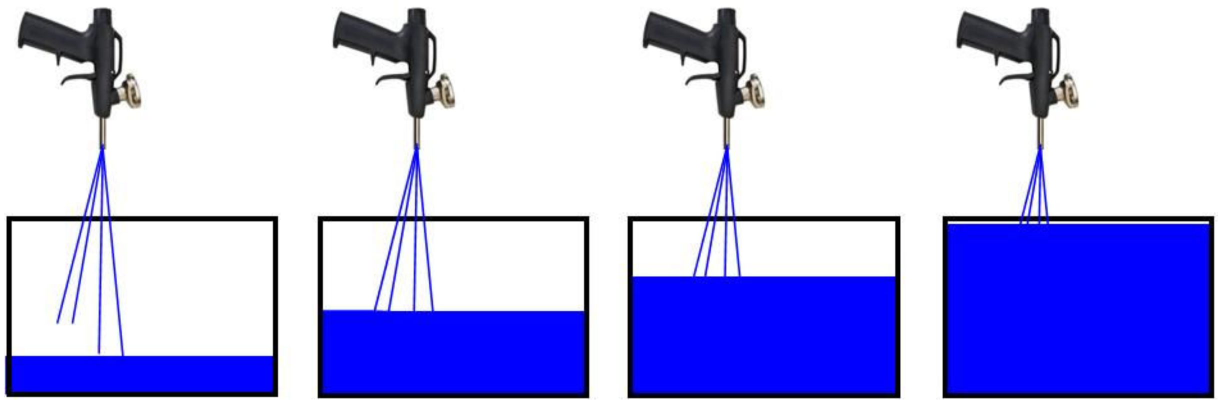

Fig. 2: The action of slow-rise polyurethane foam in a mould.

In-place Density & Yield

In-place Density refers to the apparent cured density of the foam as it exists in the final form, or structure, into which it is dispensed. This will generally be higher than the free-rise density of the foam, and will vary depending on the actual amount of foam that is dispensed into a cavity of fixed volume.

In-place density is important because the final strength and physical properties of the foam will be improved and optimized by increasing the in-place density of the foam.

The in-place density may be further increased by dispensing a higher amount of foam into the mould than is theoretically needed to fill it, based on the free-rise density calculations. This process is referred to as "packing" the foam.
Proper mould venting can reduce mould pressure and help keep densities lower by allowing the gasses and products to exhaust and flash.

Slow-rise foam is recommended to be dispensed to an in-place density of 32 kg/m^3 in order to achieve the optimum physical properties.

It is possible to fill to slightly higher or lower in-place densities; depending on the specific application requirements, mould strength and orientation.

Product Yield is affected by in-place density; in that a higher apparent density will yield less volume of foam. The following equation can be used for estimating the desired In-place density:

Desired in-place density X Volume of Cavity = Amount of chemical required

For example: 32 kg/m^3 X .057 m^3 = 1.8 kg.

Mould Pressure

Mould pressure is difficult to predict and guideline. However, there will be mould pressure exerted by any pour-in-place foam in nearly all applications.

Therefore, *all* moulds need to be designed with stays or braced in some way. The amount of clamping required is dependent on the application and the desired in-place density - The higher the density; the higher the pressure. Pre-testing of a sample panel will give an indication as to the amount of stays or bracing required for a particular mould design.

In general, the more foam that is put into the mould, the higher the mould pressure and subsequently, the stronger the fixturing that is required. **Remember, all systems will develop mould pressure.**

Three major considerations which will affect mould pressure and determine how efficiently a mould is filled:

1. Mould size
2. Orientation
3. Mould venting

Application Shot Time

The term 'Shot Time' refers to the length of time necessary to dispense the desired amount of foam into the cavity or mould.

The Shot Time can be roughly estimated by first knowing the volume of the mould together with the desired In-place density of the foam.

The following calculation shows how this information can be used to determine the approximate shot time in seconds:

(Cavity Size X In-Place Density) / Weight dispensed in one minute = Shot Time in minutes.

The actual shot time will also depend on several other factors such as:

- Chemical temperature
- Application temperature
- Amount of chemical remaining in the system

Accurate shot times are best determined by controlled trials and test samples.

Mould Orientation and Size

Mould orientation refers to the position of the mould and the direction that the foam will be poured into and rise within the mould.

There are two basic positions used to describe mould orientation:

- Horizontal pour
- Vertical pour

Vertical pour describes a panel that is longer in its height - or vertical direction - than its thickness. For example: Think of a door standing on edge where the foam would have to flow to the top to fill completely. A horizontal pour is orientated where the longest dimensions are in the horizontal direction. For example: The same door laying on a table with the thickness in the vertical direction.

Most mould types, other than panels, will follow similar principles as these simple examples. As a general rule, the foam does not have to work as hard when the mould is oriented horizontally, which makes this the preferred mould position in many applications. This is because the foam will only need to rise a shorter distance and the cell structure will then tend to be stronger, since the foam cells are less elongated in the direction of rise.

Mould orientation is the most important consideration when determining the specific requirements for applying foam in a ‘pour-in place’ application. The best results are dependent on this and other factors mentioned, and are best determined by controlled trials and testing in order to achieve the required results as part of the design process.

Proper mould venting can reduce mould pressure and help keep densities lower by allowing the gasses and products to exhaust and flash. Always provide sufficient air escape holes to allow the rising foam to push out any trapped gasses as the mould is filled.

Post Shrinkage or Expansion Prevention
All materials exhibit some expansion or contraction according to temperature changes. Polyurethane foam systems are subject to volume changes under extreme conditions due to the cellular structure and the closed cell nature of the product, in addition to the normal expansion/contraction caused by temperature differentials.

Dimensional stability tests should be carried out in order to insure that the foam will perform as expected. It is important to consider the various factors in the application stage that can affect the product's ultimate strength: Namely the ‘in-place’ density, temperature and mould orientation.

The In-place Density is a property which will greatly affect the strength properties; since the higher the density, the higher the strength of the foam, or the more resistant the foam is to environmental changes. The In-place density may vary, but is tested at a nominal 32 kg/m^3 density for comparison and specification purposes. Higher In-place Densities may increase physical properties but, at the same time, will reduce the cost-effectiveness of the product, as well as produce higher mould pressures and reduce flow-ability. Correspondingly, lower in-place densities may increase the likelihood of volume changes under extreme conditions.

Also, mould orientation - which forces the foam to rise a long distance - will tend to elongate and stretch the cells, which can also weaken the ultimate strength of the foam. Proper ratio of chemicals is, of course, critical to achieving optimum performance, and must be assured for success in any application.

Effects of Temperature
The correct air temperature plays a critical role in the performance of any two-component polyurethane foam system. Both the liquid chemical temperature and the ambient temperature, (i.e. mould temperature), will affect system performance.
The recommended chemical temperature is in the range between 24$^{\circ C}$ - 29$^{\circ C}$. The chemical must be stabilized within this range. If the chemicals are not within this range they may dispense in the incorrect ratio and thereby leading to poor quality foam.

Moisture Vapour Transmission - Perm ratings
Water; in its low energy state – liquid - does not permeate through polyurethane closed cell foam. Correspondingly, in its high energy state – vapour - its permeance is retarded significantly. Because of its very low moisture vapour transmission properties, polyurethane foam may be considered a 'vapour retarder' when applied in sufficient thickness. However, there is no definition of what constitutes a vapour retarder versus a vapour barrier; but the outstanding insulating and air barrier properties of polyurethane foam make it an excellent solution to the problem of moisture condensation and humidity build-up in properly designed applications.

British Standards associated with the insulation of walls

BS 4841-1:2006 - Rigid polyisocyanurate (PIR) and polyurethane (PUR) products for building end-use applications. Specification for laminated insulation boards with auto-adhesively or separately bonded facings.

BS 4841-2:2006 - Rigid polyisocyanurate (PIR) and polyurethane (PUR) products for building end-use applications. Specification for laminated boards with auto-adhesively bonded facings for use as thermal insulation for internal wall linings and ceilings.

BS7456 - Stabilization and thermal insulation of cavity walls.

BS 7457:1994 - Specification for polyurethane (PUR) foam systems suitable for stabilization and thermal insulation of cavity walls with masonry or concrete inner and outer leaves.

BS 8216:1991 - Code of practice for use of sprayed lightweight mineral coatings used for thermal insulation and sound absorption in buildings.

BS EN 12086:1997 - Thermal insulating products for building applications. Determination of water vapour transmission properties.

BS EN 13165:2001 - Thermal insulation products for buildings. Factory made rigid polyurethane foam (PUR) products.