The Glass Fiber Step "Smartstep", a New Generation of Escalator Steps

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Key Words: escalator, coloured steps, glass fiber-reinforced thermoplastic material, plastic injection moulding

ABSTRACT:

Escalators not only transport people in malls, department stores, fair- and convention centers, but by means of their attractive design they also encourage visitors to look around. Hence the coloration of the steps has been a long standing request of architects and customers. But traditional lacquer was too quickly damaged, resulting in an unattractive look of the step band. The new „smartstep" however, made of a completely dyed material solves this problem; in addition it offers a number of new creative possibilities by combining the coloured step body with demarcation- or decoration strips of a different colour.

1 GENERAL

Today's escalator steps are usally made of die-casted aluminum. Although this design still has potential for cost reduction, limits are set by the need for cost-intensive servicing or even replacement of the die after tens of thousands of castings. In addition, worn paint coatings and dirt adhesion in the surface pores spoil the appearance of the steps.

This is particularly true of colored step painting, which is why colored steps have remained an exception. Since the mid-1980s designers have been looking into the use of plastic as an alternative material for escalator steps. The first tests used die-casting dies, but the results showed that a material-compatible approach was required.

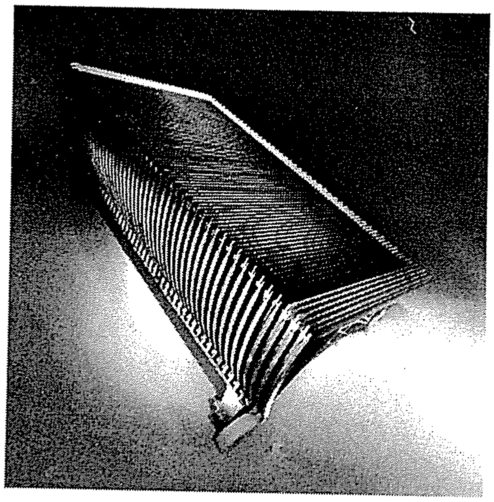
Earlier this year, the idea was turned into a marketable product when Thyssen Fahrtreppen GmbH presented the first ever escalator with steps made from a new, glass fiber-reinforced thermoplastic - developed in close cooperation with Bayer AG - at the Hanover Fair. A major feature of this solution is that it offers greater benefits at virtually the same cost.

2 REQUIREMENTS

The same basic dimensional requirements apply to glass fiber steps as to die-cast aluminum steps. The steps must run exactly through the fixed comb; in the horizontal section of the step band the step treads must be level and terracefree, and at the transition from horizontal to inclined section and vice versa two consecutive steps must mesh smoothly. Further requirements relate to ride comfort.

As a result, key functional dimensions are toleranced to within tenths of a millimeter. This applies in particular to the relative position of the axles to one another and to the step bodies, to the flatness of the tread, and to the surface shape and radius of the riser.

Figure 1
Smartstep for the new Schalke 04 soccer stadium



Overall length and width and the cleat pitch on steps and risers are also subject to close tolerances. Maintaining the required angle between the axles and the step sides and between the step sides and the tread and riser is also a key feature. All these tolerances are extraordinarily close for both die castings and injection moldings of this size.

European escalator standards require non-metallic steps to be made of materials that are not easy to ignite. As fire protection regulations have not yet been harmonized throughout Europe, national regulations still apply. In Germany, escalators are governed by the regulations for building materials. The test simulates the burning of a waste paper basket in a corner of a room. Under these conditions the spread of fire and heat must be restricted. Three ten-minute tests are carried out on four test specimens in a fire shaft ('Brandschacht' test). The specimens must not burn down to beyond a critical residual length.

Escalator steps must be able to withstand the loads involved in normal use without becoming deformed and impeding the proper function of the escalator. For this reason, regulations stipulate static and dynamic load tests to be performed on the steps.

The results of these tests on die-cast aluminum steps were well known, but it was only possible to draw limited conclusions about a similar design in the new base material. A comparison of the two materials reveals that they are of similar mechanical strength but that plastic is considerably more elastic than aluminum (Fig. 2).

Figure 2
Material characteristics

Material	Tensile Strength N/mm^2	E-Modul N/mm^2
Aluminum	150	75.000
Thermoplastic	130	12.500

3 DEVELOPMENT

3.1 Design

Consequently, when developing a polymer step it was necessary to take a completely different approach to the design of die-cast steps. Nonetheless, the appearance of the step is determined by key functional dimensions, while attention was also paid to the practical aspect of interchangeability.

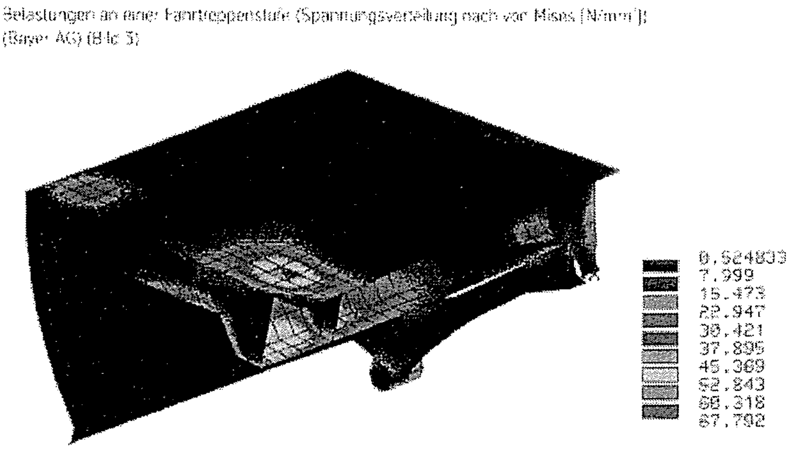


Figure 3
Loads acting on an escalator step (stress distribution according to – von Mises (N/mm²)) (Bayer AG)

Structural constraints in the escalator rule out any major change to the geometry of the steps. Moreover, the plastic injection molding process places tight limits on wall thicknesses. Initial work concentrated on strength requirements as an important parameter in material selection. The critical strength zones on escalator steps are the points at which the axles are attached and the rear reinforcing rib, as shown in the FEM analysis in Fig. 3. Whereas the axle support zone could be optimized by the use of radii and ribbing, the strength of the rear edge of the step posed a more serious problem from the outset. However, initial considerations involving a tubular rear rib revealed the feasibility of a design without metallic reinforcing elements.

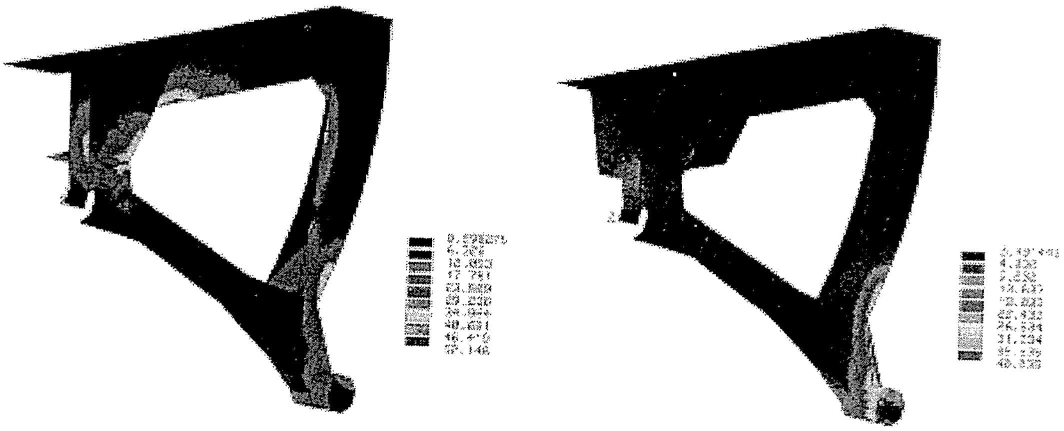
These high strength requirements led to the selection of a special polyester material with a high proportion of very fine glass fibers cut to lengths of less than 1 mm. During processing these fibers align themselves in the direction of material flow, i.e. in a well-designed mold the fibers are largely oriented in the same direction.

3.2 Strength

FEM analyses were carried out on the basis of these material data, leading to a gradual optimization of the mold in terms of lower costs and shot weights. Key factors impacting on mold costs are the number of sliders and the length of the retraction stroke. In this respect the same requirements apply as for die-cast steps, so it seemed logical to provide similar mold splitting solutions. The stiff tubular section at the rear edge was therefore replaced by a U-shaped section, open to the rear and with latticed stiffeners.

The guiding principle was to apply exactly the same requirements as for aluminum steps. This means examining the static and dynamic loads on the treads, the load on the riser and a variety of localized loads. Analyses of several design variants revealed that the stresses involved could be handled (Fig. 4).

Figure 4
Stress distribution for different variants (Bayer AG)



Spannungsverteilung für unterschiedliche Varianten (Bayer AG) (Bild 4)

3.3 Deformation

In terms of deformation, too, it was necessary to satisfy the same requirements as for die-cast steps. While deformation of the axle supports affects only the running properties, deformation of the riser and tread are critical for safety. Excessive deformation would open up gaps between the steps or between steps and the fixed comb in which limbs or clothing could become trapped. For this reason, extensive analyses were carried out with a variety of load situations to check the deformation of all critical points.

The strength differences between aluminum and polyester/glass fiber can be offset by ribbing and increased wall thicknesses, but the difference in elasticity is considerably greater. Whereas the step displays substantial stiffness at the front edge and in the riser, the rear edge has to be reinforced by ribbing connected to a stiff support profile. Molding a sufficiently stiff profile from the base material would involve filling the available space with a complex ribbed structure. Rear edge deformation is shown in the FEM analysis in Fig. 5.

Berechnung der Verformung an der Hinterkante einer Fahrtreppe (Bayer AG) (Bild 5)

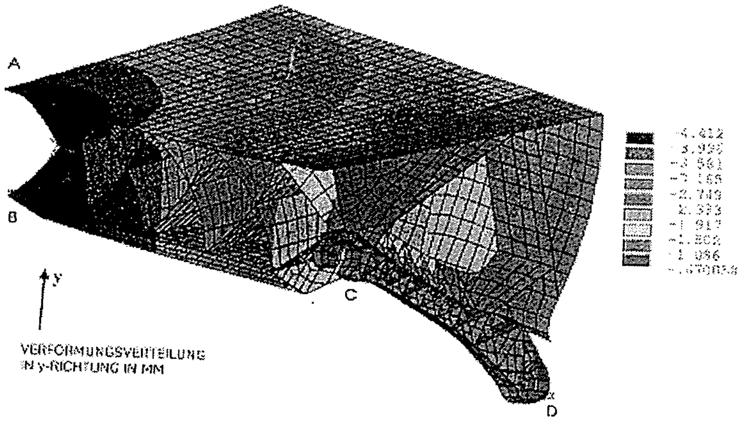
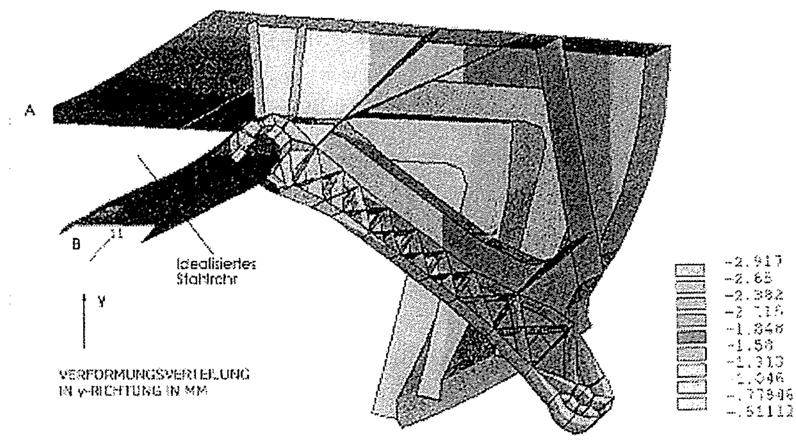


Figure 5
Analysis of rear edge step deformation (Bayer AG)

As a far more effective alternative, it was decided to integrate a steel tube in the reinforcing rib along the rear edge. Deflection is reliably reduced to the required level using a light, relatively thin-walled tube (Fig. 6), which also provides an additional reliable connection between the two axle support points.

Integrating the steel tube solved the deformation problem, reduced overall weight and considerably simplified the injection mold, which also reduced the production cycle time.



Optimierung des Verformungsverhaltens durch Integration eines Stahlrohres (Bayer AG) (Bild 6)

Figure 6 Optimized deformation characteristics through integration of a steel tube (Bayer AG)

3.4 Dimensional accuracy

The highly complex kinematics of escalator steps coupled with the essential safety requirement of minimal clearance between the steps and fixed elements mean that even with die-cast aluminum steps, tolerances for repeat accuracy in the casting process are uniquely close for components of this size. For cost reasons alone, machining should be avoided where possible; nonetheless, following die casting the treads of aluminum steps always have to be leveled, which is not applicable to injection molded parts.

Once cooled, injection molded components allow no further forming and should never be machined. Repeat accuracy in parts having the same material composition and glass fiber orientation is generally very good. However, depending on the material selected, differing material accumulations will result in differences in shrinkage. So one of the important challenges facing the materials experts at Bayer was to develop a new compound uniting the good strength properties of the polyester with good shrinking characteristics. Following final empirical corrections to the mold dimensions to eliminate deviations in the tenths of a millimeter range, it is now possible to produce high-precision parts without the need for reworking. This has set new standards for plastic components with shot weights of 10 kg and edge lengths of one meter. The level of accuracy comfortably exceeds that of die-cast parts and thus satisfies the essential precision requirements for individual components in modern escalators.

3.5 Material

Once the manufacturability of a suitable part had been established, the material had to satisfy the requirements of use in an escalator.

3.5.1 Color

For decades, the color of die-cast steps has been based exclusively on practical considerations. Silver paint is commonly used in Europe as the base material is of the same color and damage to the paint is not visible. Black is the standard color used in Asia as it is particularly insensitive to dirt. Colored painting is chosen only in exceptional cases as scratches quickly make it unattractive.

Manufacturing steps from glass fiber-reinforced plastic now makes it possible to produce through-colored step bodies. A wide range of pigments can be added to the base material; alongside black, Thyssen's color range includes blue, green and red (Fig. 7).

Figure 7 Escalators with Smartsteps in the standard colors red, green and blue

Unlike die castings, the surface of the glass fiber step is free of pores. As a result, dirt adhesion is reduced, and the steps can be cleaned at acceptable cost to retain the full effect of the color.

Safety regulations in many countries call for yellow demarcation lines along three edges of the steps; in Asia, plastic inserts are generally used for demarcation. As lowering the tread cleats around the edges was advantageous for the mold design, all glass fiber steps feature a 40 mm edge zone on three sides made of parts of the same material and colored either yellow, the same color as the step or one of the other available step colors. This opens up broad possibilities for color design wherever yellow stripes are not a legal requirement. Colors can be combined to provide escalator steps matching customer color schemes. Colored steps can also be used as part of a wayfinding system in building complexes.

3.5.2 Fire protection

From the outset, special attention has been paid to fire protection when selecting step materials. Fires within the escalator itself or in buildings can spread to the steps, and although escalators are generally not to be used as emergency escape routes, they should not pose an additional risk to passers-by in the case of a fire.

Regulations specify limited-combustible materials for steps which must satisfy the German DIN 4102 B1 standard or the North American UL 94 V-0 standard. Appropriate certification has now been obtained for the Smartstep.

Fire resistance is provided by the very high glass fiber content and by the addition of fireproofing agents in the material which decompose under the influence of heat and cause the material to extinguish itself as soon as the fire acting on the steps is out.

3.5.3 Chemical resistance

Polyester was selected as the base material not only because of its strength but also due to its high chemical resistance. Alongside normal environmental influences, escalator materials also come into contact with a variety of cleaning agents as well as oil and grease from drive equipment. The material used was tested with a wide range of cleaners and lubricants.

4 ADVANTAGES OF THE INJECTION MOLD

With a slider configuration similar to that in die-casting dies established as the optimum solution, the size and weight of the injection mold are very similar to those of a die-casting die (Fig. 8). To ensure long tool life, high-quality heat-resistant steels must also be used for injection molding tooling. In view of the lower processing temperatures, however, the material is not subjected to the high stresses which cause noticeable surface cracking in die-casting dies after the production of several tens of thousands of parts and necessitate repairs.

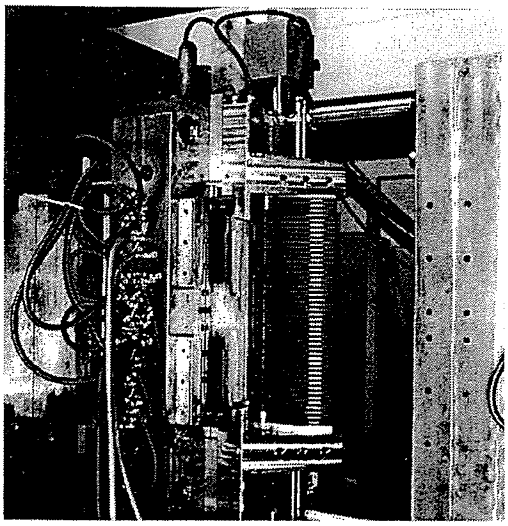


Figure 8
Injection mold for Smartstep

A second factor resulting in longer tool life is the lower flow speed of the material, which reduces erosion. Corresponding mold designs permit highly uniform mold filling with an even melt front. As a result, the mold fills cleanly right into the ends of the cleats without overflowing. The melt fronts predicted in the mold flow analysis can be verified by injecting partial fillings.
The lower injection temperature also enables the gaps between the slider guides to be designed more closely and kept constant. Burring, frequently a cause of rework on die-cast parts, must be avoided on injection-molded components.

These advantages make it possible to maintain the high surface quality of injection moldings over a period in which die-casting dies would have had to be replaced several times.

5 TESTING

Following a brief optimization phase for the injection molder, reliable process control was achieved from the outset, producing steps of a dimensional accuracy and quality suitable for functional tests. After minor adjustments they were installed directly in an escalator and ran perfectly.

5.1 Static testing

In accordance with European escalator regulations, the deformation tolerances of the steps are tested by applying a single load to the center of the tread with the step in horizontal and inclined positions. To ensure the highest quality, Thyssen performs this test using higher loads than prescribed and also extends it to the riser.

All load tests to Thyssen's load specifications were successfully completed and certified by TÜV Hamburg (technical inspectorate). In comparison with aluminum die cast steps, the glass fiber step displays greater stiffness, while both designs achieve similar breaking loads.

5.2 Dynamic testing

Dynamic testing is carried out on the inclined step only, with the single load applied 5 million times. Here again, testing was carried out at TÜV Hamburg to the higher Thyssen load specifications and the successful results certified.

An important factor in this test is that the test frequency is matched to the thermal load capacity of the plastic material. Testing remains within the frequency range specified in the regulations.

5.3 Fire testing

As already stated, the base material passed the UL 94 V-0 flammability test and the DIN 4102 B1 test for the flammability of building materials.
In addition to this, a 1:1 test was carried out on a step loaded with weights to simulate its usability in a fire (Fig. 9). The source of the fire was a highly combustible material ignited below the step. After five minutes the fire was extinguished, the weights removed and the step examined for damage. The step remained undamaged. Slight deformation took place during cooling, but it was still fully usable.

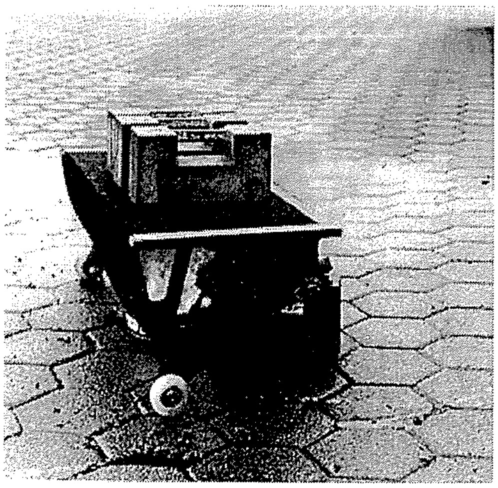


Figure 9
Fire test on a Smartstep loaded with weights

Also worthy of note during the fire tests is that despite being subject to flames from below for several minutes, the tread barely heated up and could still be stepped on without any problem, whereas the aluminum step becomes too hot after two to three minutes. This means that in case of fire, the Smartstep remains usable for a longer period of time.

6 PRACTICAL EXPERIENCE

Following months of trials on a test facility in the factory, the escalator installed in the ThyssenKrupp pavilion at the 1999 Hanover Fair was the first system with glass fiber steps to be put into public use (Fig. 10). Many users failed to notice not only that the steps were of an unusual color for Germany but also that the entire step was a revolutionary development. Further features include a more pleasant sound when stepping onto the escalator, an improved non-slip surface and a dampened tread.

Figure 10
Escalator with Smartsteps in the ThyssenKrupp pavilion at the Hanover Fair

The workshop at the manufacturer's factory also benefits from the advantages of this step. Smaller dimensional variations facilitate the setting of the guide systems; the lower weight of the steps makes them easier to handle; and there is no damage to paintwork during assembly.

Escalators with blue, green and red steps have now been delivered to numerous European customers, and the first overseas orders have also been received. The key factor for customers is the overall appearance of the step, with the high-quality surface showing the color to its best advantage. This gives architects the opportunity to integrate the escalator more effectively into its surroundings or design steps in the customer's color scheme.
One good example is the German soccer team Schalke 04: the predominant club color is blue, so it goes without saying that the Thyssen escalators to be installed in the new Schalke stadium will also have blue steps.

The first Hamburg installation gave the opportunity to watch passengers using blue Smartsteps for the first time. A good deal of them realized the breakthrough, looked at the steps from different positions, bent down and felt, stating that here not only the color is new.