CASE STUDY

NECK CONNECTOR FOR A CHILD'S DOLL

The Mattel Toy Corporation produces millions of "Barbie" dolls each year. Mattel has experienced a 0.2% return rate on Barbie dolls because the head separates too easily from the body during use, and cannot easily be reassembled. Though percentage-wise, this return-rate is low, it translates into an estimated $14.7 million (US) in lost revenue.

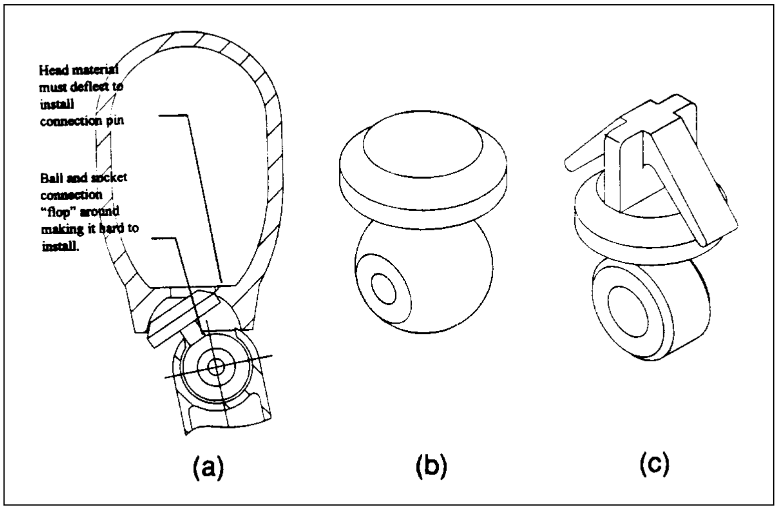

Fig 1 (a) the original neck connector design; (b) the difficulty of inserting the original connector (c) the current design

The problem lies with the design of the neck connector (Figure 1(a)). The spherical ball moulded on one end of the connector fits into a socket in the doll's body. It is made from an acetal plastic,

FUNCTION	Coupling with 3 degrees of freedom
OBJECTIVE	Minimise mass
CONSTRAINTS	Dimensions fixed (no free variables) Must not fail under bending loads Easy to form (mouldable) Not too expensive

Table 1 Design Requirements

and is permanently attached to the body (ABS plastic) during manufacture. The head, made from PVC plastisol, is soft and pliable. The hole in the base of Barbie's head expands enough during assembly to allow insertion of the connector. Because of the poor lead-in shape on the original design for the connector (Figure 1(b)), the head is difficult to install and too easy to remove.

To combat this problem, Mattel modified the connector to make assembly easier and removal of the head more difficult, giving the current design (Figure 1(c)). The wings guide the neck when it is pushed into the head; and they expand once they are in, locking the two together. This design has the effect of increasing the peak stress on the stem which links the upper and lower part of the neck. Before, if it were pulled or twisted excessively, the connector would dislodge from the head. Now that this is prevented, the stem could break. The design requires that the articulation of Barbie's head remains as before, meaning that the dimensions of the stem cannot be changed much. We therefore seek the material best able to resist decapitation.

The loading on the neck is complex; it is subject to both bending and tension. Bending is probably the most dangerous because the local stresses are higher. Its weight is important: if too heavy, the doll could be more stable on its head than on its feet, with an adverse influence on sales.

We seek materials which are strong and are light. And since material cost is important for components which are made in very large numbers, we seek materials which are relatively cheap and easy to form. Table 1 summarises the requirements.

The Model

The load which can be carried safely by a stem of fixed section, whether loaded in tension or bending, is proportional to its failure strength. Two types of failure are possible: plastic deformation, and fracture.

The mass of the neck – with all dimensions fixed – simply scales with the density, ρ, and its strength scales with its elastic limit, σ_{el}.

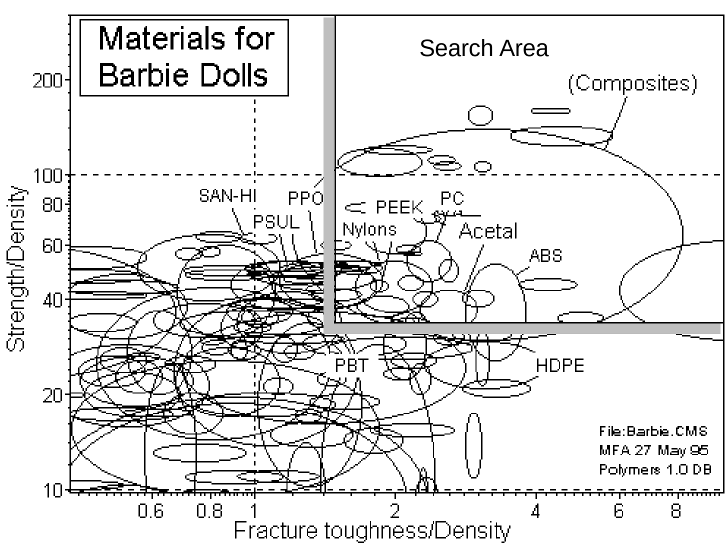

Fig 2 Chart of M_1 vs M_2 using the polymers database

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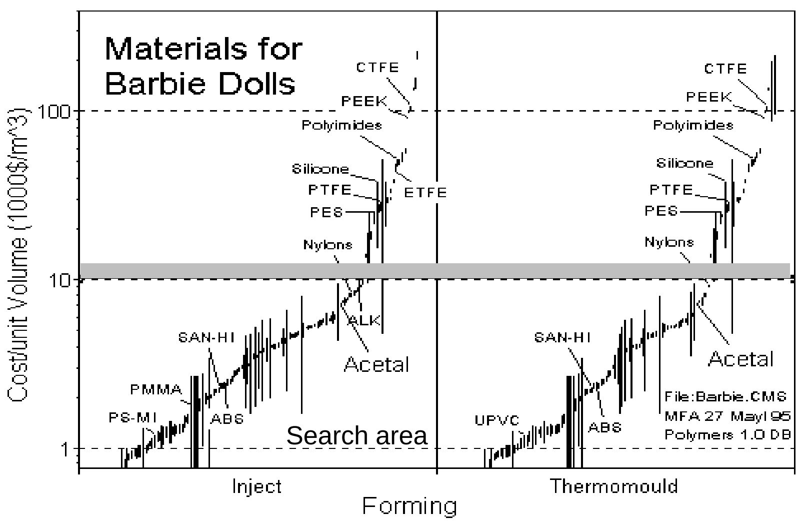

Fig 3 A bar-chart of cost against forming, using the Polymers database.

Light materials which resist plastic failure are those with high values of $M_1=\sigma_{el}/\rho$. Those which are light and resistant to brittle fracture have high values of $M_2 = K_{Ic}/\rho$, where K_{Ic} is the fracture toughness.

We seek mouldable materials with high values of both indices, and which cost no more than Acetal.

The Selection

A preliminary search, using the Generic database, points to polymers as having the best combination of performance and manufacturability. Figures 2 and 3 show a two-stage selection using the Polymers database. The first is a chart of σ_{el}/ρ against K_{Ic}/ρ; the selection lines isolate materials with high values of M_1 and M_2. The second stage shows cost per unit volume plotted against forming methods. Materials which can be injection moulded or thermo-moulded have been selected. The selection line passes through the data for the currently-used material, Acetal.

The materials which pass both selection stages are listed in Table 2. PEEK and Polyimides have excellent values of M_1 and M_2 but they are eliminated by the stringent cost requirement we have applied in Figure 3. Other selection stages could be added. Nylons absorb water, degrading their strength. A stage based on 'water absorption' would reveal this. Stiffness and flexibility, as well as strength, might be a consideration; then a stage in which Young's modulus, E, is plotted against yield strain σ_{el}/E would enable further refinement of choice.

Postscript

A subset of the materials selected here coincides with traditional materials: high strength plastics, though composite materials bear further investigation. Barbie's neck (as usual) has other design considerations: the need to be brief restricts us here to the simplest. Clever choice of shape, combined with that of material can lead to further insights. For these, see reference (2).

MATERIALS PASSING ALL STAGES
Acetal (AT) High Impact
Acrylobutadienestyrene (ABS) – High Impact
Acrylobutadienestyrene (ABS) – Medium Impact
Nylon 6/10 (Polyamide, PA)
Nylon 6/6 (Polyamide, PA)
Polybutylene Terephthalate (PBT)
Polycarbonate (PC) – Fire Retardant
Polypropylene (PP) Homopolymer
Polyethylene terephthalate (PET) – amorphous
Polypropylene oxide (PPO)
Polypropylenes (PP)
Polystyrene (PS) – High Impact
Polyvinylchlorides (PVC) – Rigid
Styrene Acrylonitrile (SAN) – High Impact

Table 2 Selection Results

References

1. Modern Plastics Encyclopedia '94, Mid-November 1993 issue, Volume 70, Number 12. (McGraw Hill, 1993).

2. R Klausner, ML Smith, C Carrol, Sakaguchi, and OS Es-Said (1995) 'Material property database facilitated design of neck connector for a childrens doll'.