Chapter 2 Selection of Materials and Processes

1. Figure 2.24 shows the side view of a modern hollow golf driver head. The preferred weight of a driver head is 200 g and the volume is 460 cc; the latter value is the maximum allowable by the United States Golf Association. To achieve these two design specifications modern driver heads are constructed as hollow shells. Most commonly the face is manufactured separately, as shown in section on the right of the figure, and either welded or bonded to the hollow shell body. For highest ball speed off the face after impact, the face of a modern driver is designed to act as a stiff diaphragm spring. Use the material data in Table 2.5 and the diaphragm spring maximum performance parameter in Table 2.6 to determine candidate metal alloys for the face, which also possess high strength needed for golf ball impact. Since it is difficult to make modern large driver heads within the 200 g target weight, repeat the calculations using the derived parameter for best diaphragm spring property per weight. Do your selections agree with the manufacturers' material of choice for driver heads?

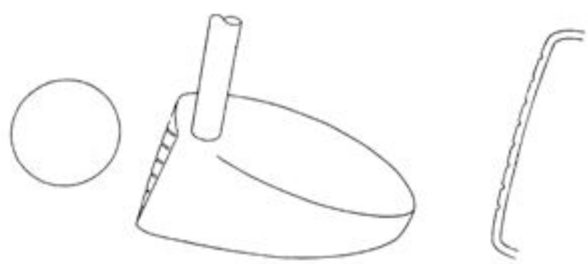

Figure 2.24

Solution: From Table 2.6, the criteria of merit for diaphragm springs are $Y_t^{1.5}/E$ for best performance and $Y_t^{1.5}/(E\rho)$ for best performance per unit weight. Comparing metal alloys from Table 2.5, which can be manufactured in thin-wall parts gives the following:

	$Y_t^{1.5}/E$	$Y_t^{1.5}/(E\rho)$
Beryllium copper	0.287	3.48×10^{-5}
Titanium	0.257	5.41×10^{-5}
Alloy steel (high strength)	0.248	3.15×10^{-5}
Magnesium	0.080	4.44×10^{-5}

Almost all modern golf driver heads are made from high-strength titanium alloys which corresponds to the ranking in the third column. The earliest metal drivers were much smaller in volume (< 300 cc compared to the current USGA 460 cc limit). Material weight was not an issue for these smaller heads and the material of choice was alloy steel. The second column shows little discrimination between alloy steel and the much more expensive choices of titanium or beryllium copper.

2. Figure 2.25 shows a support platform for a precision electrical instrument. The platform is 100 mm high, and the platform base and top have outer dimensions 75x75 mm. The square cutout in the top plate has dimensions 50 x 50 mm. The platform is to be made from an electrically conductive metal.

Use the procedures in Sections 2.3 and 2.4 to identify all candidate primary processes from the list in Fig. 2.3. The top and bottom surface of the platform must be flat and parallel. Any other surface on the part may have slight taper or draft, if required, for particular primary process choices. Some of the features on the finished part may be assigned to secondary machining processes to increase the list of candidate primary processes. For these cases add an ordered list of the required secondary processes to the primary one, to create a simple production plan. When considering machining from stock as a possible option, also consider if a primary process could be used to eliminate the need for machining some of the required main features.

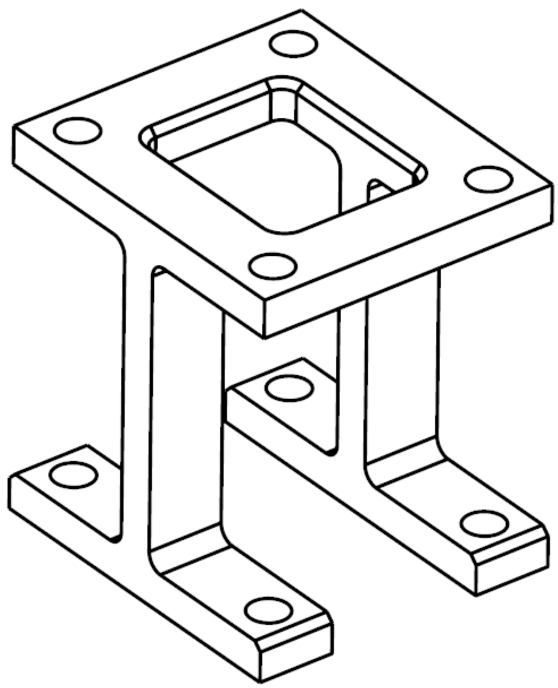

Figure 2.25

Solution: The platform has the following shape attributes:

Depress:	Yes Yes	(two directions: vertically and between the legs)
UniWall:	Yes	
UniSect:	Yes	(I – section across width)
AxisRot:	No	
RegXSec:	No	
CaptCav:	No	
Enclosed:	No	
No Draft:	No	

With reference to Table 2.2, and excluding processes which cannot process conductive material, gives candidate primary processes;

Sand casting	Closed die forging
Investment casting	Machining from stock
Die casting	

Note that because of the depression (through hole) across the width, closed die forging is unlikely to be cost effective: see suffix 'a' in column 2 of Table 2.2.

The direction of mold opening for sand casting or die casting would be in the vertical direction (to produce the required flat and parallel top and bottom faces), with side cores (sand casting) or side die action (die casting) to form the side depressions and the main slot between the legs. For investment casting two dies would likely be used for the wax pattern pieces; one for the top plate and one for the T-section legs. All three casting processes could produce the screw clearance holes. However, sand casting would be unlikely to provide precise enough surfaces for instrument mounting. The production processes list would be:

Primary Process	Secondary Processes
Investment casting	none
Die casting	trim flash (see Ch. 10)
Sand casting	mill top and bottom faces

For machining from stock with significant production volume, consider investment in a die plate for hot extrusion of the required I-section shape. The process list for this might be:

1. Cut to length; 2. Mill large center 'slot' across width; 3. Mill rectangular hole in face; 4. Drill holes

3. A version of the support platform in Fig. 2.25 is required for aerospace use, for which its electrical conductivity should be as high as possible combined with minimum weight. Assume that all of the section thicknesses should have the same value, *h*, so that the part volume can be expressed approximately in the form $V = C_0 h$, where C_0 is a constant. Using electrical resistivity, $\gamma \ (\Omega - cm)$, and density, $\rho \ (g/cm^3)$, determine the derived parameter which represents electrical current flow/ weight. Use this parameter to compare different possible materials. Refer to materials handbooks for resistivity and density data, or use web material databases such as www.matweb.com. Since alloying elements can have a significant effect on electrical resistivity, compare only pure metals in this exercise as a starting point for investigation of candidate alloys. (*Hint: assume an applied voltage, v, and conductive paths up through the legs of width, w, and length, L are fixed by the design. Also assume that leg thickness h changes with change of material to obtain the required level of conductivity. Write an expression for current flow, I, in* *terms of these parameters and the variable thickness, h. Use this with an approximate expression of part weight to obtain the required result.*)

Solution:

Consider the conductivity path up one of the legs. I = current flow in amps.

From Ohm's law $I = v/R$, (1)

where v is the voltage (given) and R is the resistance of the conductor. From the definition of resistivity,

$$R = \frac{L\gamma}{wh}, \text{ ohms} \quad (2)$$

Conductor volume is:

$$V = Lwh$$

and weight, $W = Lwh\rho$ (3)

Substituting (2) into (1) gives:

$$I = \frac{vwh}{L\gamma} \quad (4)$$

and eliminating h between (3) and (4) gives:

$$\frac{I}{w} = \left(\frac{v}{L^2}\right)\left(\frac{1}{\gamma\rho}\right)$$

Hence for best performance per unit weight we require: $\left(\frac{1}{\gamma\rho}\right)_{max}$

A comparison of likely pure metal candidates is:

Metal	ρ (g/cc)	γ (ohm – cm)	$^1/_{(\gamma\rho)}$
Copper	8.83	1.7 x 10^{-6}	6.7 x 10^{4}
Aluminum	2.70	2.7 x 10^{-6}	1.3 x 10^{5}
Magnesium	1.74	1.74 x 10^{-6}	1.3 x 10^{5}
Silver	10.49	1.6 x 10^{-6}	5.9 x 10^{4}
Gold	19.32	2.2 x 10^{-6}	2.4 x 10^{4}

Thus it appears that aluminum and magnesium alloys are equally likely candidates.

4. Figure 2.26 illustrates the outer housing of rotor assembly, of which a production volume of 100,000 is required. The assembly is designed to spin at high speed during which the housing is subjected to high tensile stresses. Preliminary designs calculations suggest that the housing could be made of aluminum alloy with a wall thickness in the range of 2.0 to 3.0 mm depending on the selected alloy. The wall thickness may be different for other candidate materials but low strength materials requiring an excessively thick wall should be avoided. A good surface finish of approximately 50 μ in is required.

The part is 13 cm high. The large diameter is 20 cm which steps down to 17.5 cm at the midpoint. The bottom of the housing is open and the top has large hole 12.5 cm diameter in the center surrounded by twelve 1.5 cm diameter holes.

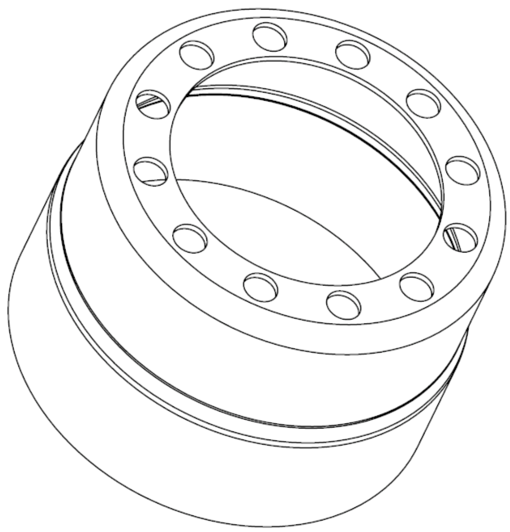

Figure 2.26

Use the procedures in Sections 2.3 and 2.4 to identify all candidate primary processes, for manufacture of the housing, from the list in Fig. 2.3. The inner and outer main surfaces may have slight taper or draft, if required, for particular primary process choices. Some of the features on the finished part may be assigned to secondary processes. For these cases add an ordered list of the required secondary processes to the primary one, to create a simple production plan.

(Hint: First eliminate processes from Table 2.2 on the basis of shape attributes. This will leave a relatively large set of candidate processes. Next review these candidates in Table 2.1 to check the requirements of part size, surface finish, process limitations and associated materials against the design requirements.)

Solution: The rotor housing has the following shape attributes:

Depress:	Yes No
UniWall:	Yes
UniSect	Yes
AxisRot:	Yes
RegXSec:	No
CaptCav:	No
Enclosed:	No
No Draft:	No

Using Table 2.2 only eliminates:

- Blow molding (extrusion)
- Blow molding (injection)
- Rotational molding
- Hot extrusion
- Rotary swaging

The requirement for strength equivalent to 2 to 3 mm thick aluminum alloy eliminates:

- Structural foam molding

The requirement for a surface finish of approximately 50 μin (referring to Table 2.1) eliminates:

- Sand casting
- Hot forging

Reference to the 'Process limitations' column and 'Part size' columns of Table 2.1 eliminates:

- Cold heading
- Impact extrusion
- Hot forging
- Pressing and sintering

The remaining candidate processes are:

- Investment casting
- Impact extrusion
- Injection molding
- Sheet metal stamping
- Metal spinning
- Machining
- ECM
- EDM

Note: Wire EDM is excluded since it can only generate near 2-D profiles.

Since 100,000 are required machining, ECM and EDM will certainly be non-competitive with respect to the forming and casting processes. Possible manufacturing sequences are:

Primary processes	Secondary processes
Injection molding	None
Die casting	Trim flash
Investment casting	None
Sheet metal stamping	Punch holes
Metal spinning	Punch holes

5. Saturn Automobile Corporations is one of only a very few car manufacturers to replace some of the commercial quality steel body panels with injection molded ones. The material they chose to use is glass-reinforced polycarbonate, blended with ABS for improved mold flow characteristics. The elastic modulus of this blended reinforced thermoplastic is $E=5\ GN/m^2$, and the yield stress is $Y_t=80\ MN/m^2$. The steel panels had a nominal thickness of 1mm and corresponding material properties of $E=200\ GN/m^2$, and $Y_t=300\ MN/m^2$.

Use an appropriate derived parameter to investigate Saturn's marketing claim that the thermoplastic panels are more 'ding' resistant. Determine the wall thicknesses Saturn would have needed to use to obtain the same panel stiffness as the sheet steel ones being replaced.

(Hint: 'ding resistance' is determined by the diaphragm spring quality of the panels, so use the appropriate derived parameter for comparison. Refer to Section 2.5.3 for help with the last part of this problem.)

Solution:

The 'ding resistance' is governed by the diaphragm spring quality of the panels. From Table 2.6 this is defined by the derived parameter $(Y_t^{1.5}/E)$. Comparison of the two materials gives:

Material	Y_t	E	$Y_t^{1.5}/E$
Commercial quality steel	300	200	26
PC/ABS glass reinforced	80	5	143

These values amply support Saturn's claims.

From section 2.5.3, the thickness, *h,* of the material B to replace material A for equivalent panel (bending) stiffness is

$$h_B = h_A\left({}^{E_A}/_{E_B}\right)^{1/3} = 1.0\left({}^{200}/_{5}\right)^{1/3} = 3.4\ mm$$

6. Review the equations relating the maximum center load which can supported by a simply-supported beam with length *L*, width *w*, thickness *h*, and yield strength in tension Y_t. If length and width are fixed by the design, show that two beams *A* and *B* (or equivalently two plates) will have the same load carrying capability if

$$h_B^{\ 2}Y_{tB} = h_A^{\ 2}Y_{tA} \text{ or equivalently } h_B = h_A(Y_{tA}/Y_{tB})^{1/2}$$

Use this relationship as an approximate test of the requirement for equal or improved bending strength of the Saturn panels, described in Problem 5, compared to the sheet steel ones.

Solution: From any strength of materials text, for a simply supported beam of length, *L*, width, *w*, and thickness, *h*, the maximum stress produced by a center load *F* is:

$\sigma = \frac{FLh}{I}$, where the second moment of area $I = \frac{wh^3}{12}$

Therefore $\sigma = \frac{3FL}{wh^2}$

For maximum load, F_{max}, corresponding to maximum tensile stress, Y_t,, this gives:

$$Yh^2 = (3F_{max}L/w)$$

Assuming the right-hand side of this equation is fixed by the design specification, then for alternate materials A and B to satisfy the same specifications we require:

$$Y_{tB}h_B^2 = Y_{tA}h_A^2 \text{ or } h_B = h_A(Y_{tA}/Y_{tB})^{1/2}$$

For substitution PC/ABS (glass reinforced) with 1mm thick commercial quality steel panels requires:

$$h = 1.0\left(\frac{200}{80}\right)^{1/2} = 1.94\ mm$$

7. Suggested class project: Study Table 2.1, which covers the more common manufacturing processes in consumer product production. Identify a product manufacturing process not included in Table 2.1. Complete an entry for your process in Tables 2.1 and 2.2. Provide references for your process information.

Solution: Left to individual student

8. Construct the Excel spreadsheet illustrated in Table 2.5. Use this to explore the best material choices for each of the 18 criteria given in Table 2.6.

Solution: Left to individual student