The Science and Engineering of Materials: Chapter 2 Exercises

Skills Learned: Unit conversion, fundamental constants of elements

Knovel Problems:

K2-1 A 2 in.-thick steel disk with an 80 in. diameter has been plated with a 0.0009 in. layer of zinc.

(a) What is the area of plating in in^2?
(b) What is the weight of zinc required in lb?
(c) How many moles of zinc are required?
(d) Name a few different methods used for zinc deposition on a steel substrate.
(e) Which method should be selected in this case?

Knovel Solutions:

(a) Search for ‘cylinder surface area’ on Knovel. In the search results, click on the text link for the *Appendix G: Geometric Formulas* in the title *Aerosol Measurement – Principles, Techniques, and Applications (2nd Edition)* (John Wiley & Sons © 2001) to see the formula for calculating the surface area of a cylinder:

Ellipsoids: oblate

surface area $= 2\pi a^2 + \frac{\pi b^2}{\varepsilon} \ln\left(\frac{1+\varepsilon}{1-\varepsilon}\right)$

volume $= \frac{4\pi a^2 b}{3}$

Right cylinder

surface area $= 2\pi r L + 2\pi r^2 = \pi d L + \frac{\pi d^2}{2}$

where L is the length

volume $= \pi r^2 L = \frac{\pi d^2 L}{4}$

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$$A = (\pi \cdot d \cdot L) + \left(\frac{\pi \cdot d^2}{2}\right)$$

Thus,

$$A = \left(\pi \cdot \frac{10000}{127} \cdot \frac{250}{127}\right) + \left(\frac{\pi \cdot (\frac{10000}{127})^2}{2}\right) = 10225.90454\ in^2$$

(b) Search for ‘zinc plating weight’ on Knovel. In the search results, click on the text link for the section *63.28.1 Calculation Procedure* in the title *Standard Handbook of Engineering Calculations (4th Edition)* (McGraw-Hill © 2005). The text below provides the equation for calculating the weight of plating metal and the density of zinc:

2. Compute the weight of metal required. The plating metal weight = (area plated, in^2) (plating thickness, in) (plating metal density, lb/in^3). For this plating job, given the density of zinc from Table 11, the plating metal weight = $(60 \times 144)(0.004)(0.258) = 8.91$ lb (4.0 kg) of zinc. In this calculation the value 144 is used to convert 60 ft^2 to square inches.

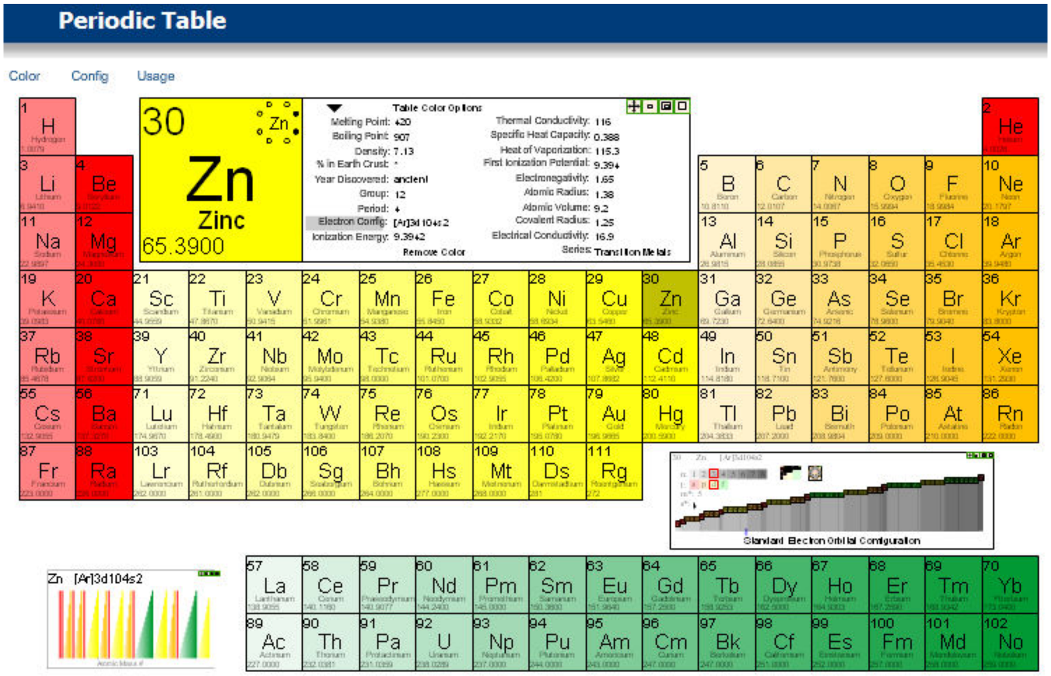
Related Calculations The efficiency of finishing cathodes is high, ranging from 80 to nearly 100 percent. Where the actual efficiency is unknown, assume a value of 80 percent and the results obtained will be safe for most situations.

TABLE 11 Electroplating Current and Metal Weight

	Time to deposit, Ah		Metal density	
Metal	0.001 in/ft^2 at 100% efficiency	0.01 mm/m^2 at 100% efficiency	lb/in^3	g/cm^3
Antimony, Sb	10.40	0.038	0.241	6.671
Cadmium, Cd	9.73	0.036	0.312	8.636
Chromium, Cr	51.80	0.189	0.256	7.086
Cobalt(ous), Co	19.00	0.069	0.322	8.913
Copper(ous), Cu	8.89	0.033	0.322	8.913
Copper(ic), Cu	17.80	0.065	0.322	8.913
Gold(ous), Au	6.20	0.023	0.697	19.29
Gold(ic), Au	18.60	0.068	0.697	19.29
Nickel, Ni	19.00	0.069	0.322	8.913
Platinum	27.80	0.102	0.775	21.45
Silver, Ag	6.20	0.023	0.380	10.52
Tin(ous), Sn	7.80	0.029	0.264	7.307
Tin(ic), Sn	15.60	0.057	0.264	7.307
Zinc, Zn	14.30	0.052	0.258	7.141

$$M = A \cdot t \cdot \rho = 10225.90454 \cdot \frac{9}{10160} \cdot 0.258 = 2.337062041\ lb$$

(c) To obtain the number of moles required, we must first find the molar mass of zinc. Go to the Periodic Table (Tools menu) and find zinc (atomic no. 30):



The molar mass of zinc in 0.1441602637 lb/mol. The number of moles is calculated as:

$$Number\ of\ moles = \frac{mass}{Molar\ mass} = \frac{2.337062041}{0.1441602637} = 16.21155498\ mols\ of\ Zinc$$

(d) Search for ‘zinc application methods’ on Knovel. In the search results, click on the text link for the section *13.4 Zinc Coatings* in the title *Corrosion (3rd Edition) Volumes 1-2* (Elsevier © 1994):

Methods of Application

The principal method for applying zinc coatings to iron and steel is hot-dip galvanising. There are four other important methods, each of which has its own particular applications; these methods are spraying, plating, sherardising and painting with zinc-rich paints. The choice of method in any given case is determined by the application envisaged, and the five processes may be said to be complementary rather than competitive, for there is usually little doubt as to which is the best for any particular purpose. Processes of applying coatings by various methods are discussed in detail elsewhere[1] and are considered in Chapter 12, and will not, therefore be considered here. The reactions inherent in galvanising tend to ensure a thick and even coating but guides to the inspection of galvanising, sherardising and zinc spraying are available[2].

The deposition methods for Zn are hot-dip galvanizing, spraying, plating, sherardising, and painting with zinc-rich paints.

(e) Search for 'zinc coatings comparison' on Knovel. In the search results, click on the text link for the section *13.4 Zinc Coatings* in the title *Corrosion (3rd Edition) Volumes 1-2*:

Table 13.7 Comparison of zinc coatings

Characteristics of coating	*Hot-dip galvanising*	*Metal spraying*	*Plating*	*Sherardising*	*Zinc dust painting*
1. Process considerations	Parts up to 20 m long and fabrications of 18 m × 2 m × 5 m can be treated. Care required at design stage for best results. Continuous galvanised wire and strip up to 1·4 m wide) in UK	No size or shape limitations. Access difficulties may limit its application, e.g. inside of tubes. Best method for applying very thick coatings. Little heating of the steel	Size of bath available. Process normally used for simple, fairly small components suitable for barrel plating or for continuous sheet and wire. No heating involved	Batch processing is mainly suitable for fairly small complex components. Semi-continuous process for rods, etc.	Can be brush, spray or dip applied on site when necessary. No heating involved. Performance varies with media used
2. Economics	Generally the most economic method of applying metallic zinc coatings 20–200 μm thick	Most economic for work with high weight to area ratio. Uneconomic on open mesh	Used, where a very thin zinc coating is sufficient. Thick coatings are expensive.	More expensive than galvanising for equivalent thicknesses. Generally used when control of tolerances is more important than thickness of coating	Low overheads but high labour element in total cost as with all paints. Thixotropic coatings reduce number of coats and hence labour costs
3. Adhesion	Process produces iron–zinc alloy layers, overcoated with zinc; thus coating integral with steel	Good mechanical interlocking provided the abrasive grit-blasting pretreatment is done correctly	Good, comparable with other electroplated coatings	Good—the diffused iron–zinc alloy coating provides a chemical bond	Good—abrasive grit blasting preparation of the steel gives best results
4. Thickness and uniformity	Normally about 75–125 μm on products, 25 μm on sheet. Coatings up to 250 μm on products by prior grit-blasting. Very uniform—any discontinuities due to poor preparation of the steel are readily visible as 'black spots'	Thickness variable at will, generally 100–200 μm but coatings up to 250 μm or more can be applied. Uniformity depends on operator skill. Coatings are porous but pores soon fill with zinc corrosion products; thereafter impermeable	Thickness variable at will generally 2–25 μm. Thicker layers are possible but generally uneconomic. Uniform coating within limitations of 'throwing power' of bath. Pores not a problem as exposed steel protected by adjacent zinc	Usually about 12–40 μm closely controlled. Thicker coatings also possible. Continuous and very uniform even on threaded and irregular parts	Up to 40 μm of paint (and more with special formulations) can be applied in one coat. Good uniformity—any pores fill with reaction products

Reviewing the above table, we find that the plating is preferred for the steel substrate of given geometry and required coating thickness.