Design and testing of Joints and bonded assemblies

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Rheology (viscosity and flow) of liquid adhesives

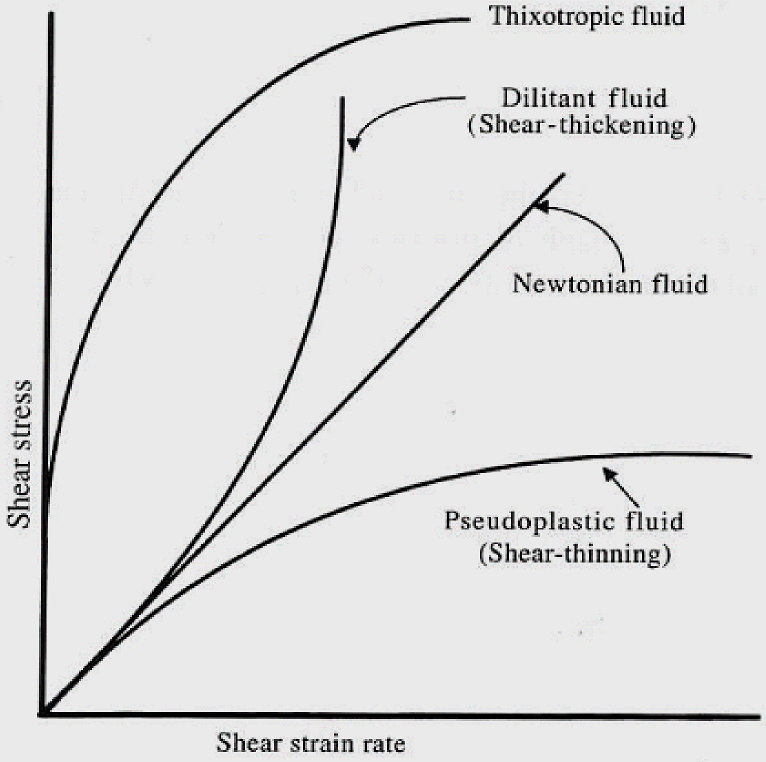
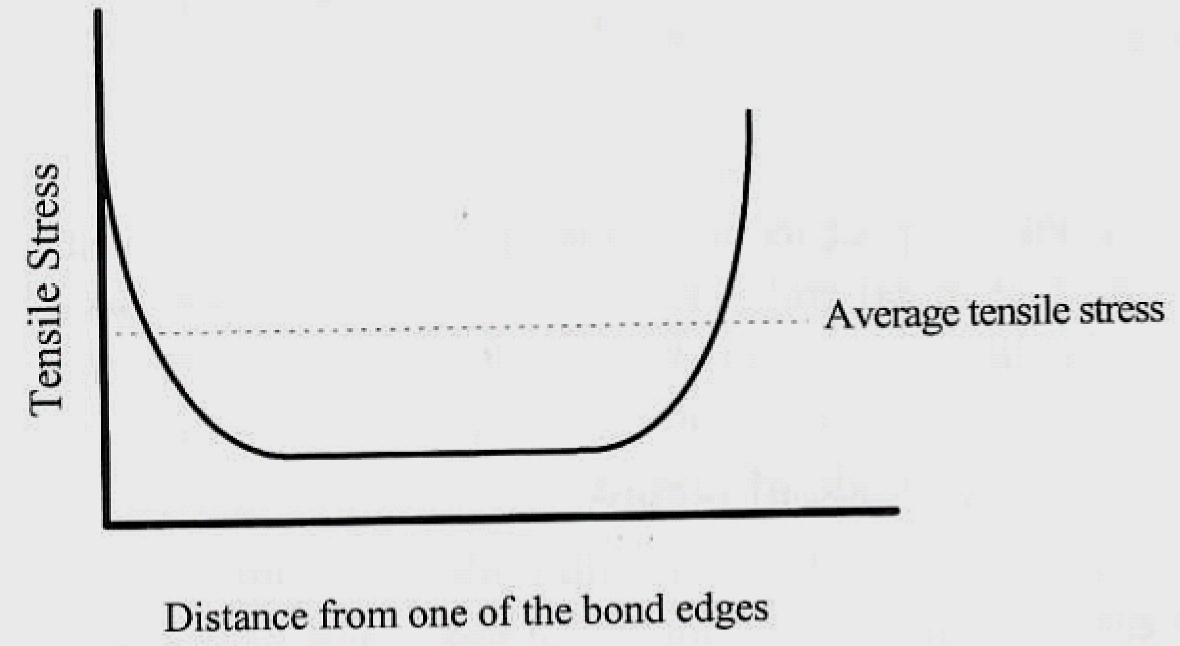


Figure 2.8 Plot of shear stress-shear strain rates for a number of different types of liquids.

Why data sheet information is risky business….



The uneven distribution of stress in a Joint – theoretical calculation (optimistic picture…)

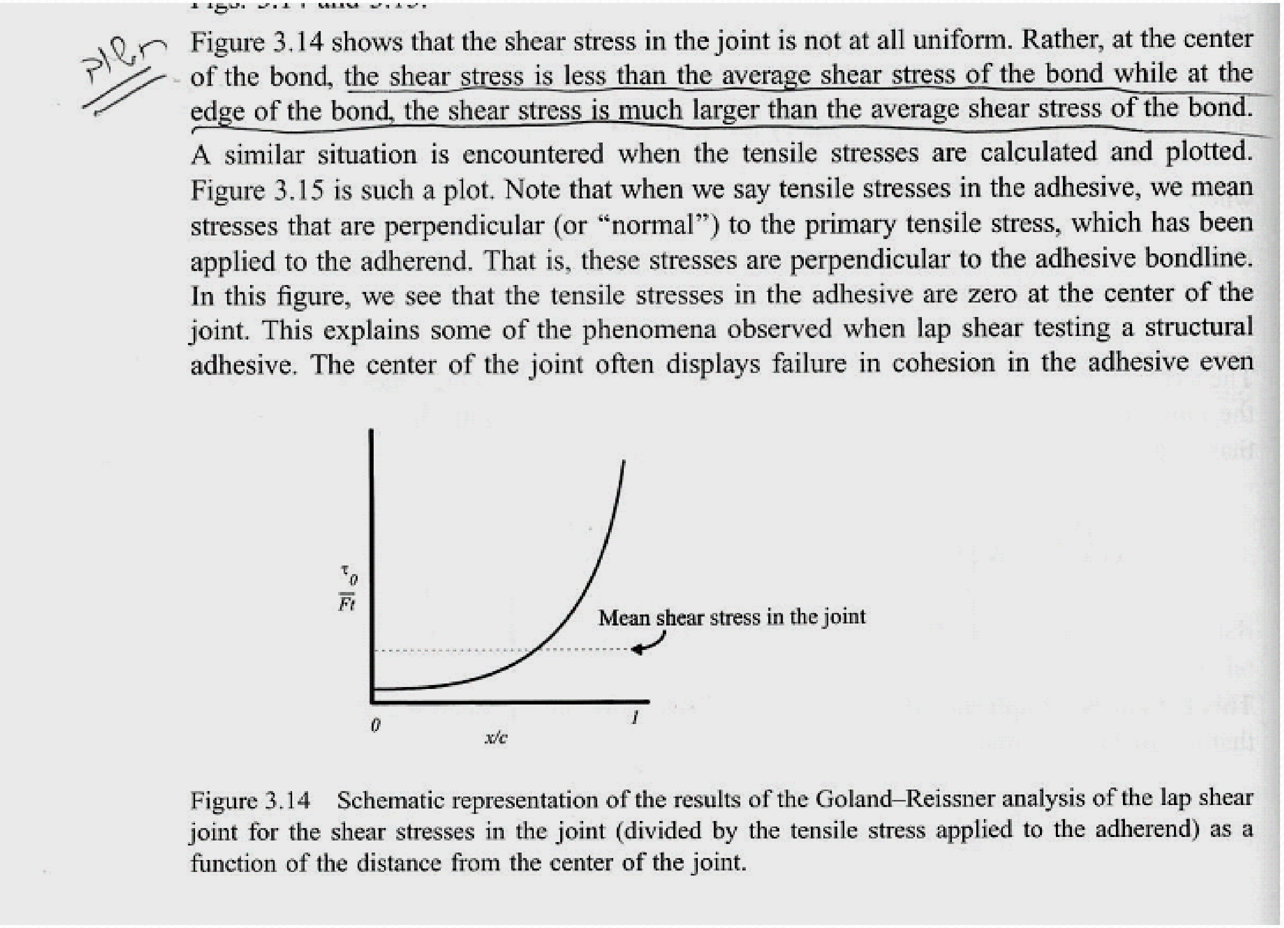


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Figure 3.14 shows that the shear stress in the joint is not at all uniform. Rather, at the center of the bond, the shear stress is less than the average shear stress of the bond while at the edge of the bond, the shear stress is much larger than the average shear stress of the bond. A similar situation is encountered when the tensile stresses are calculated and plotted. Figure 3.15 is such a plot. Note that when we say tensile stresses in the adhesive, we mean stresses that are perpendicular (or "normal") to the primary tensile stress, which has been applied to the adherend. That is, these stresses are perpendicular to the adhesive bondline. In this figure, we see that the tensile stresses in the adhesive are zero at the center of the joint. This explains some of the phenomena observed when lap shear testing a structural adhesive. The center of the joint often displays failure in cohesion in the adhesive even

Figure 3.14 Schematic representation of the results of the Goland–Reissner analysis of the lap shear joint for the shear stresses in the joint (divided by the tensile stress applied to the adherend) as a function of the distance from the center of the joint.

The uneven distribution of stress in a Joint – practical measurement (worst picture…)

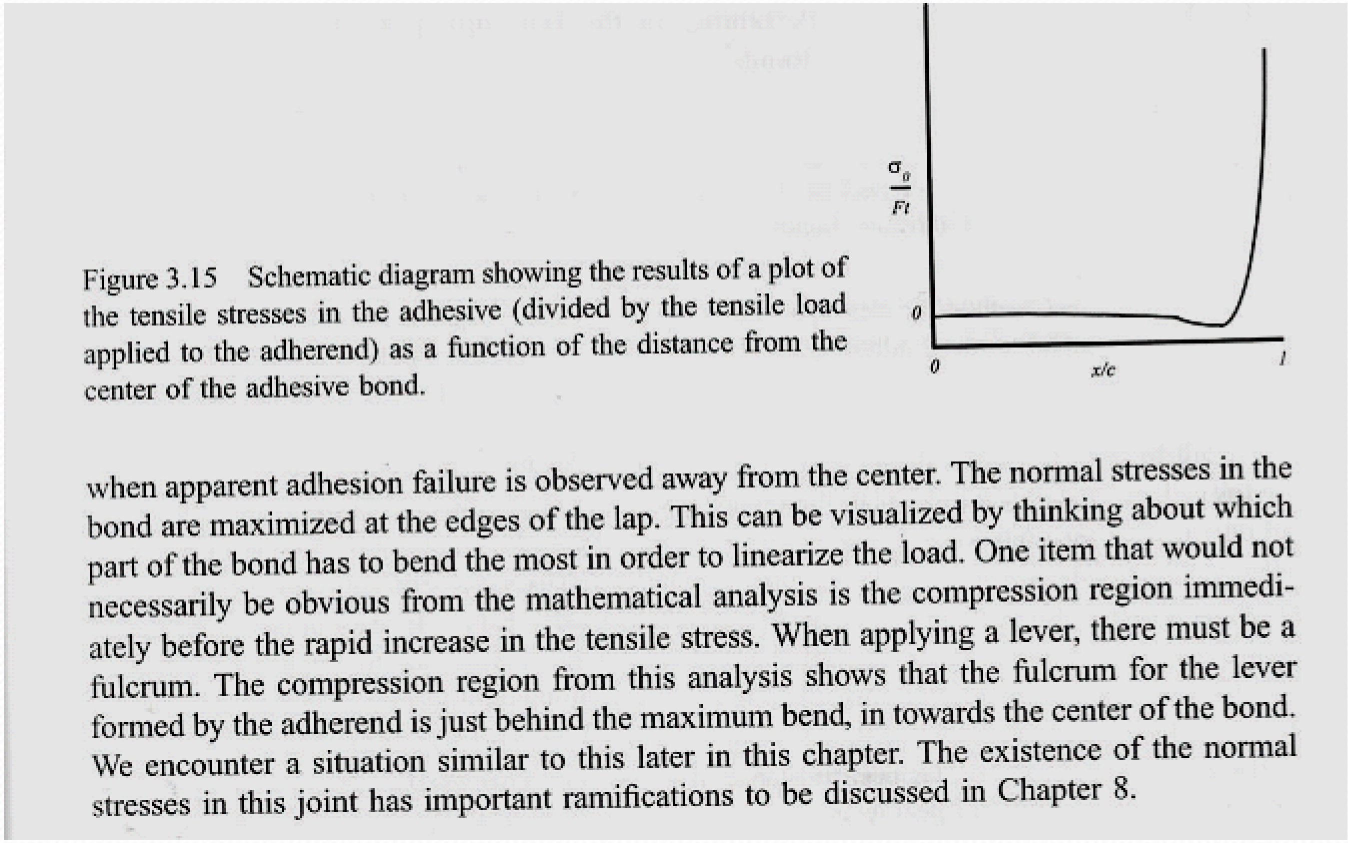
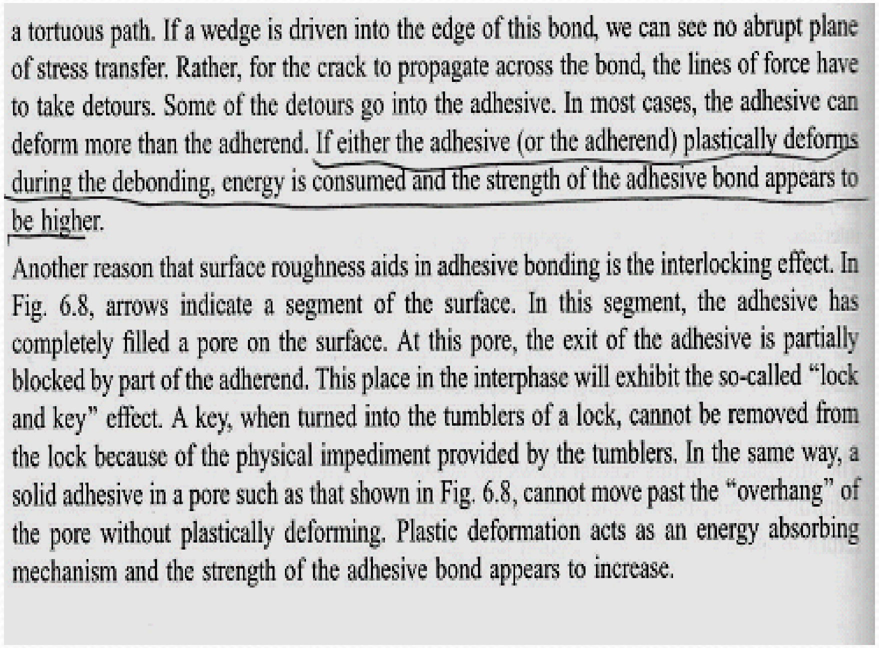


Figure 3.15 Schematic diagram showing the results of a plot of the tensile stresses in the adhesive (divided by the tensile load applied to the adherend) as a function of the distance from the center of the adhesive bond.

when apparent adhesion failure is observed away from the center. The normal stresses in the bond are maximized at the edges of the lap. This can be visualized by thinking about which part of the bond has to bend the most in order to linearize the load. One item that would not necessarily be obvious from the mathematical analysis is the compression region immediately before the rapid increase in the tensile stress. When applying a lever, there must be a fulcrum. The compression region from this analysis shows that the fulcrum for the lever formed by the adherend is just behind the maximum bend, in towards the center of the bond. We encounter a situation similar to this later in this chapter. The existence of the normal stresses in this joint has important ramifications to be discussed in Chapter 8.

Roughness – not just "mechanics"



a tortuous path. If a wedge is driven into the edge of this bond, we can see no abrupt plane of stress transfer. Rather, for the crack to propagate across the bond, the lines of force have to take detours. Some of the detours go into the adhesive. In most cases, the adhesive can deform more than the adherend. If either the adhesive (or the adherend) plastically deforms during the debonding, energy is consumed and the strength of the adhesive bond appears to be higher.

Another reason that surface roughness aids in adhesive bonding is the interlocking effect. In Fig. 6.8, arrows indicate a segment of the surface. In this segment, the adhesive has completely filled a pore on the surface. At this pore, the exit of the adhesive is partially blocked by part of the adherend. This place in the interphase will exhibit the so-called "lock and key" effect. A key, when turned into the tumblers of a lock, cannot be removed from the lock because of the physical impediment provided by the tumblers. In the same way, a solid adhesive in a pore such as that shown in Fig. 6.8, cannot move past the "overhang" of the pore without plastically deforming. Plastic deformation acts as an energy absorbing mechanism and the strength of the adhesive bond appears to increase.

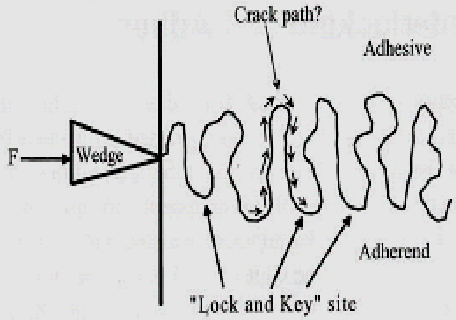
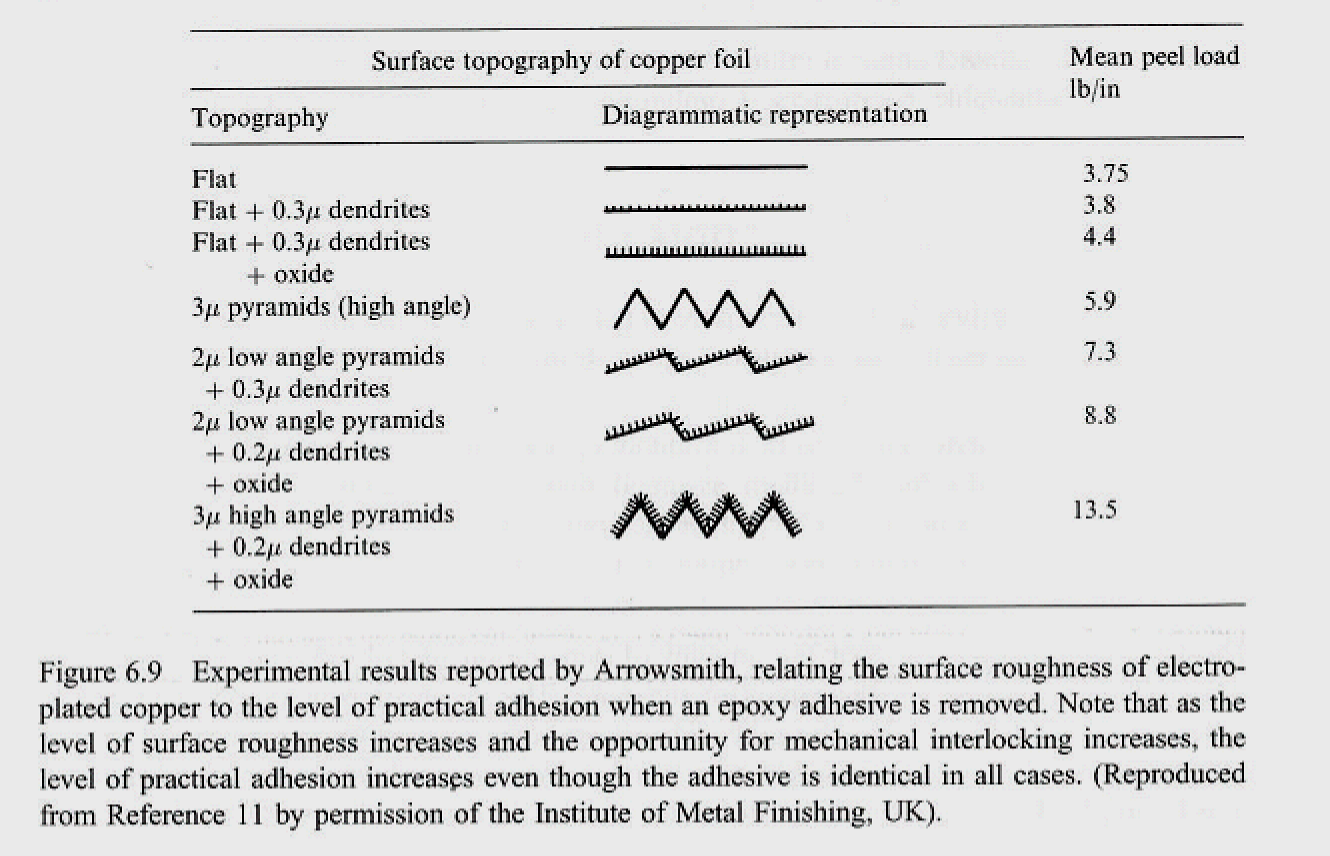


Figure 6.8 Schematic showing a tortuous interface between two adhering materials. When a Mode I loading is applied to this situation, the applied force cannot cleanly follow the path between the two adherends, but rather must make excursions. As excursions are made into the adhesive, energy can be dissipated by plastic deformation. Note also the possibility of "lock and key sites" at which points the adhesive would have to physically pass through the material of the adherend in order for separation to take place.

What “roughness” means?



Surface topography of copper foil		Mean peel load lb/in
Topography	Diagrammatic representation	
Flat		3.75
Flat + 0.3μ dendrites		3.8
Flat + 0.3μ dendrites + oxide		4.4
3μ pyramids (high angle)		5.9
2μ low angle pyramids + 0.3μ dendrites		7.3
2μ low angle pyramids + 0.2μ dendrites + oxide		8.8
3μ high angle pyramids + 0.2μ dendrites + oxide		13.5

Figure 6.9 Experimental results reported by Arrowsmith, relating the surface roughness of electroplated copper to the level of practical adhesion when an epoxy adhesive is removed. Note that as the level of surface roughness increases and the opportunity for mechanical interlocking increases, the level of practical adhesion increases even though the adhesive is identical in all cases. (Reproduced from Reference 11 by permission of the Institute of Metal Finishing, UK).

Adhesive-Substrate relations

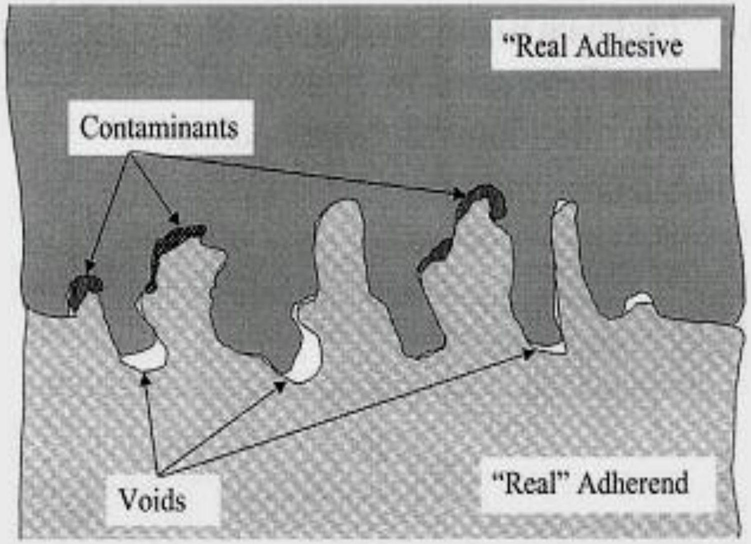


Figure 6.10 Schematic of a 'real' bonding situation in which the surface of the adherend has contaminants and in which the adhesive has a finite viscosity. Pore penetration is not complete, leaving voids at the interface. The presence of voids as well as cohesively weak contaminants, decreases the strength of the adhesive bond below its theoretical strength.

Causes for adhesion loss in interfaces

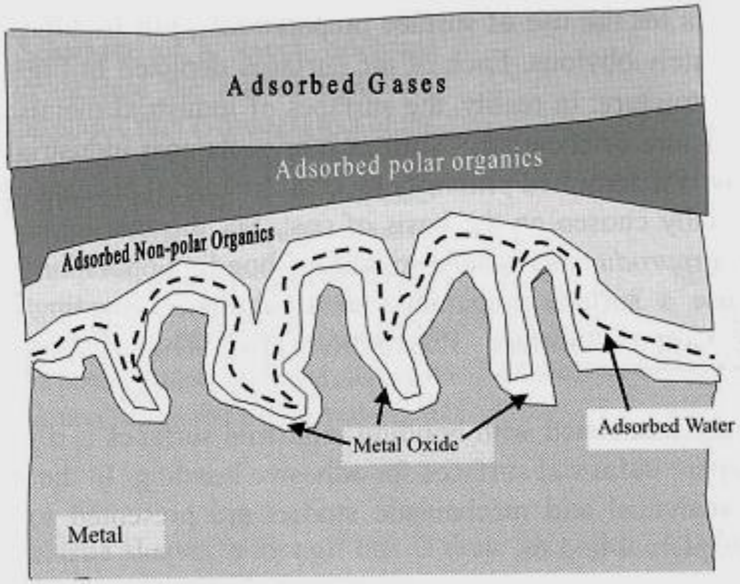


Figure 7.1 Diagram showing the layered, rough structure that could be expected on the surface of unprepared metal. Scale of surface roughness could be on the order of microns as could be the depth of the contaminants on the surface.

Thermoplastic polymer interface

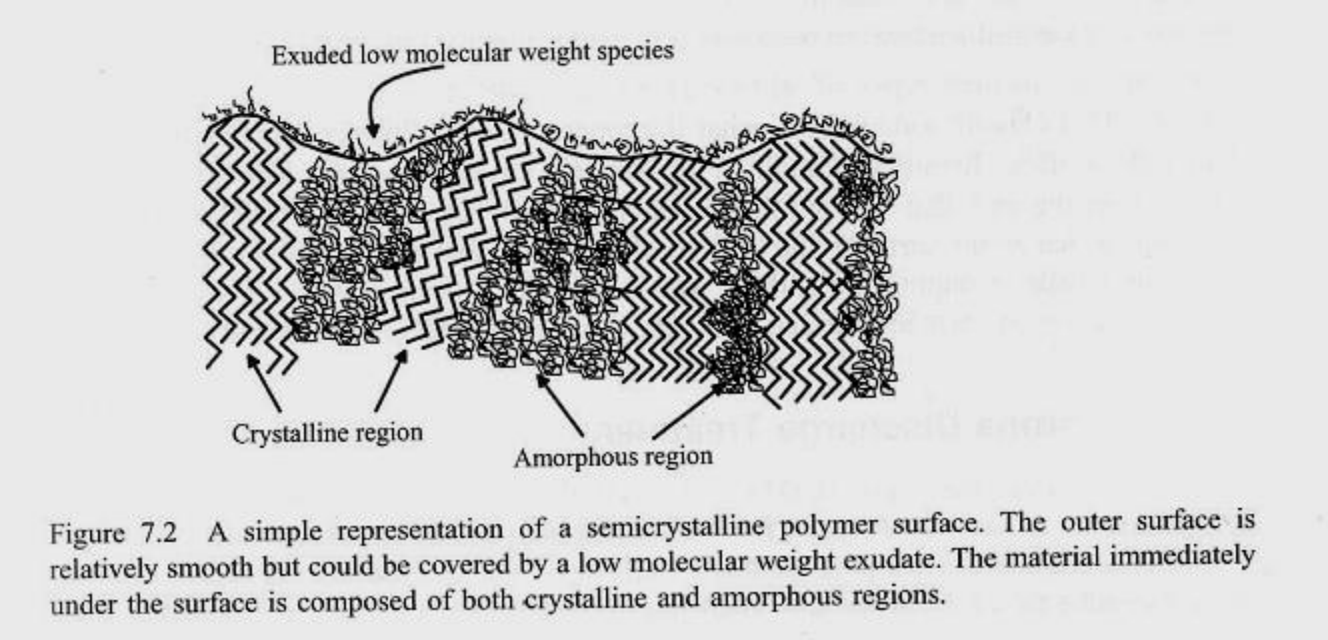


Figure 7.2 A simple representation of a semicrystalline polymer surface. The outer surface is relatively smooth but could be covered by a low molecular weight exudate. The material immediately under the surface is composed of both crystalline and amorphous regions.

Plastic materials and ease of bonding

Plastic Name	crystallinity	Ease of bonding	Recommended adhesive type
Polyamide (NYLON, PA)	high	poor	*epoxy on etched/primed surface*
Polypropylene (PP)	high	very poor	*epoxy on plasma etched surface*
Polyethylene (PE)	high	very poor	*epoxy on plasma etched surface*
Polyvinyl chloride (PVC)	low	easy	*acrylic*
Polycarbonate (PC)	low	easy	*acylic*
Acrylic (PMMA)	low	easy	*acrylic*
Styrenic (PS, ABS, SAN, ASA)	low	easy	*acrylic*
Polysulfone (PSU)	low	easy	*acrylic*
Acetal (POM)	high	very poor	*not recommended*
Polyester (PET, PETG, PBT)	high	poor	*epoxy on etched/primed surface*

The many faces (Phases) of thermosetting polymer

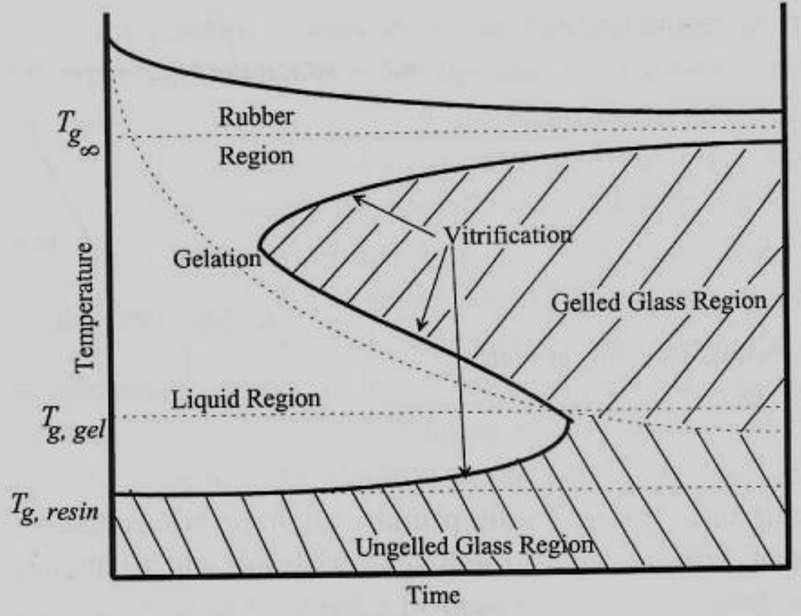
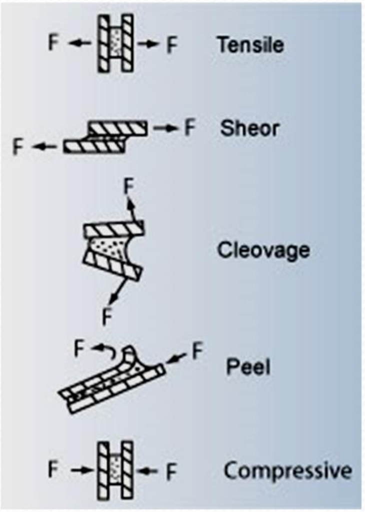


Figure 8.11 Time–Temperature–Transformation (T–T–T) diagram for a thermosetting resin system. Important regions to note are the gelled glass and the ungelled glass regions. Important demarcations to note are the gellation line and the vitrification line (redrawn from [2] by permission of Plenum Press and the author). It is important to realize that once a thermosetting resin becomes vitrified (forms a solid glass), chemical reactions essentially cease.

Types of stresses in joints



Design Of Joints

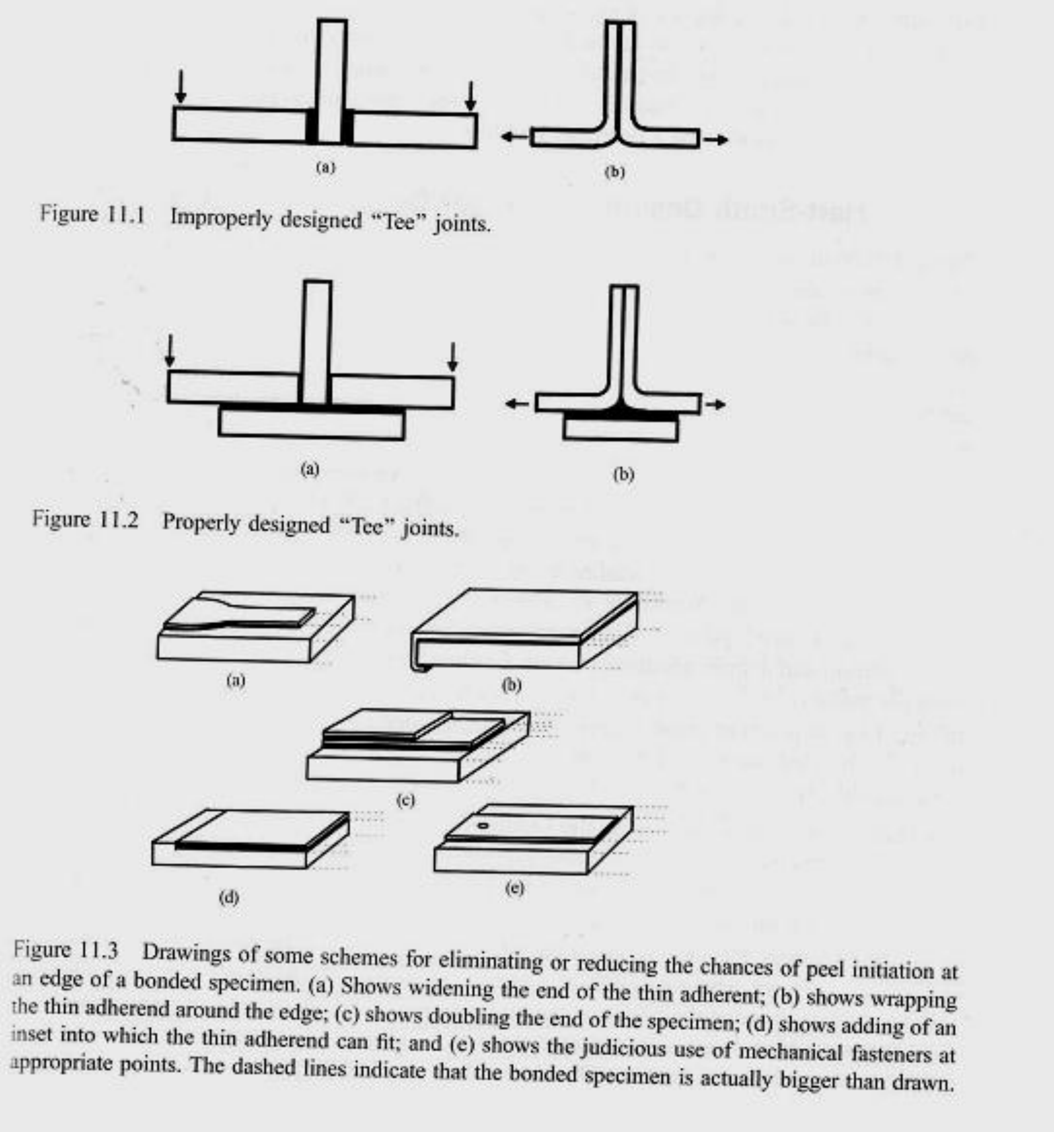
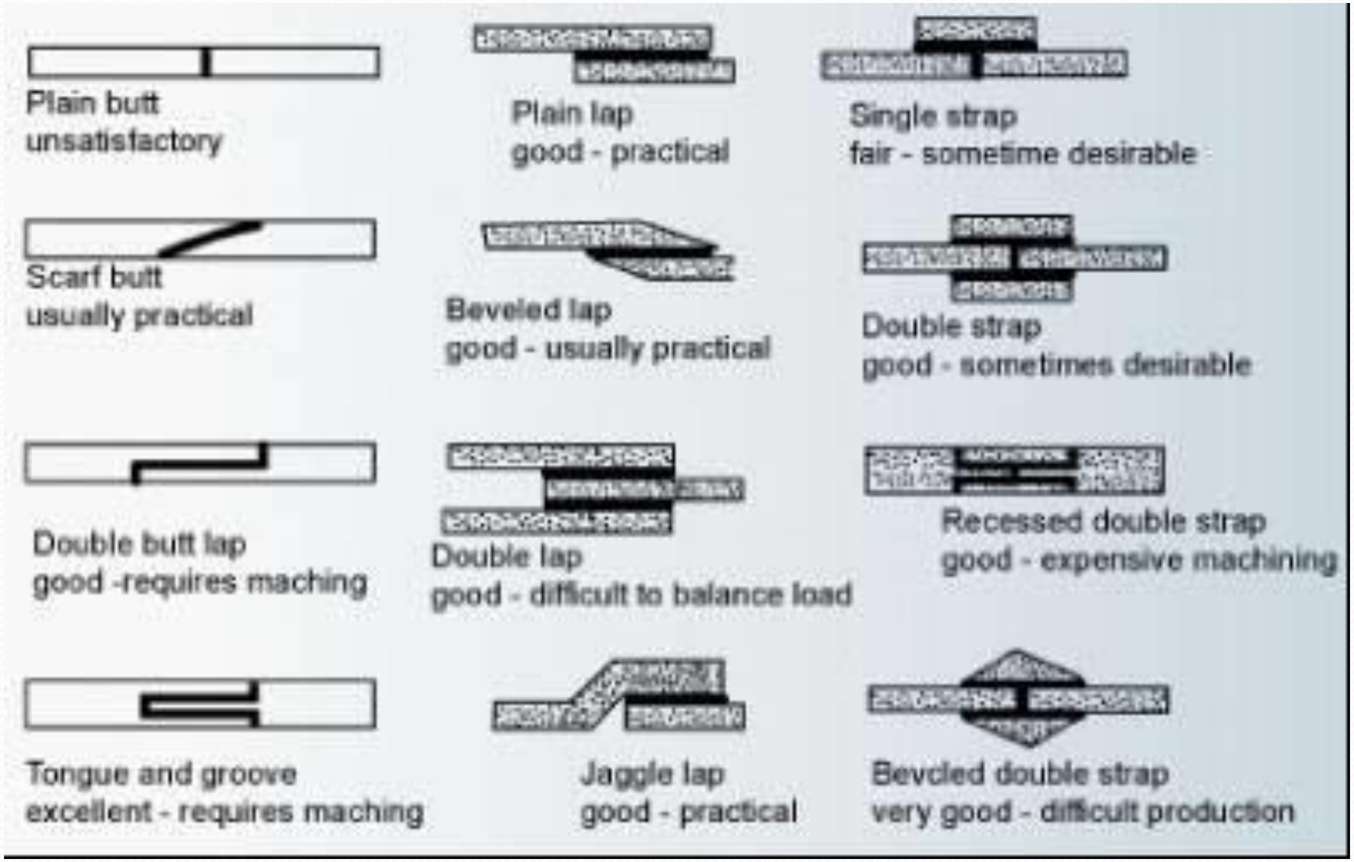


Figure 11.1 Improperly designed "Tee" joints.

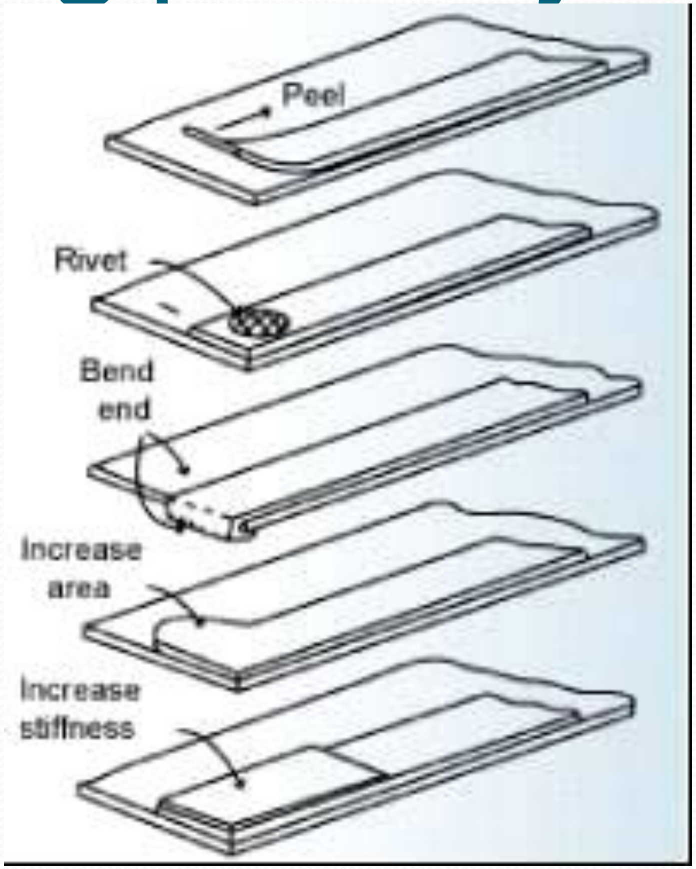
Figure 11.2 Properly designed "Tee" joints.

Figure 11.3 Drawings of some schemes for eliminating or reducing the chances of peel initiation at an edge of a bonded specimen. (a) Shows widening the end of the thin adherent; (b) shows wrapping the thin adherend around the edge; (c) shows doubling the end of the specimen; (d) shows adding of an inset into which the thin adherend can fit; and (e) shows the judicious use of mechanical fasteners at appropriate points. The dashed lines indicate that the bonded specimen is actually bigger than drawn.

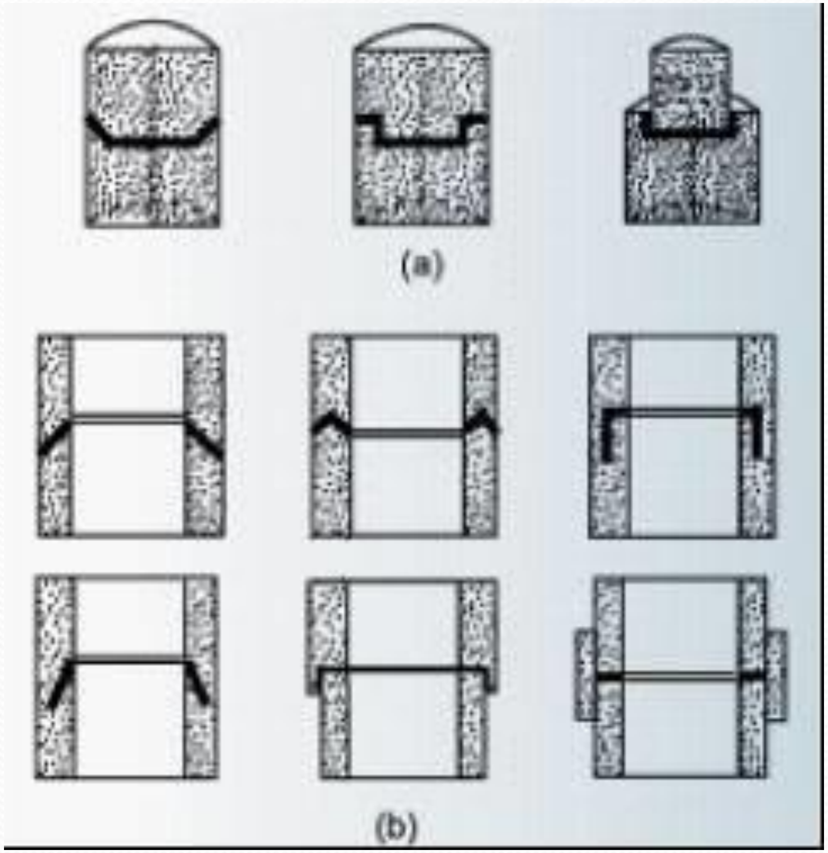
Design Of Joints



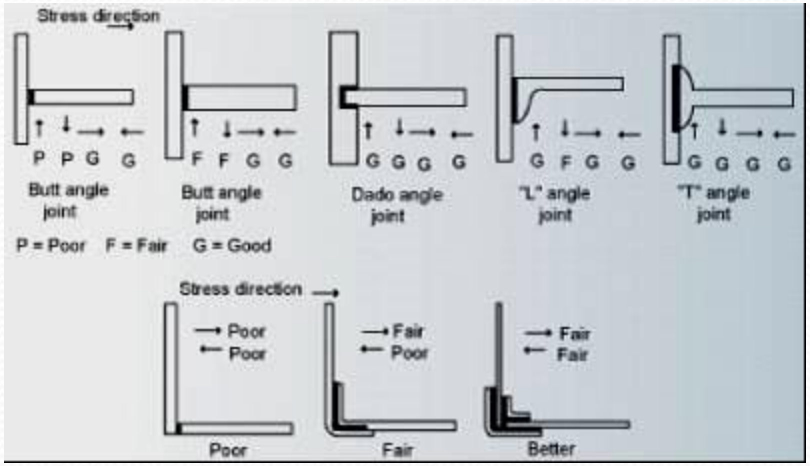
Minimizing peel in joints



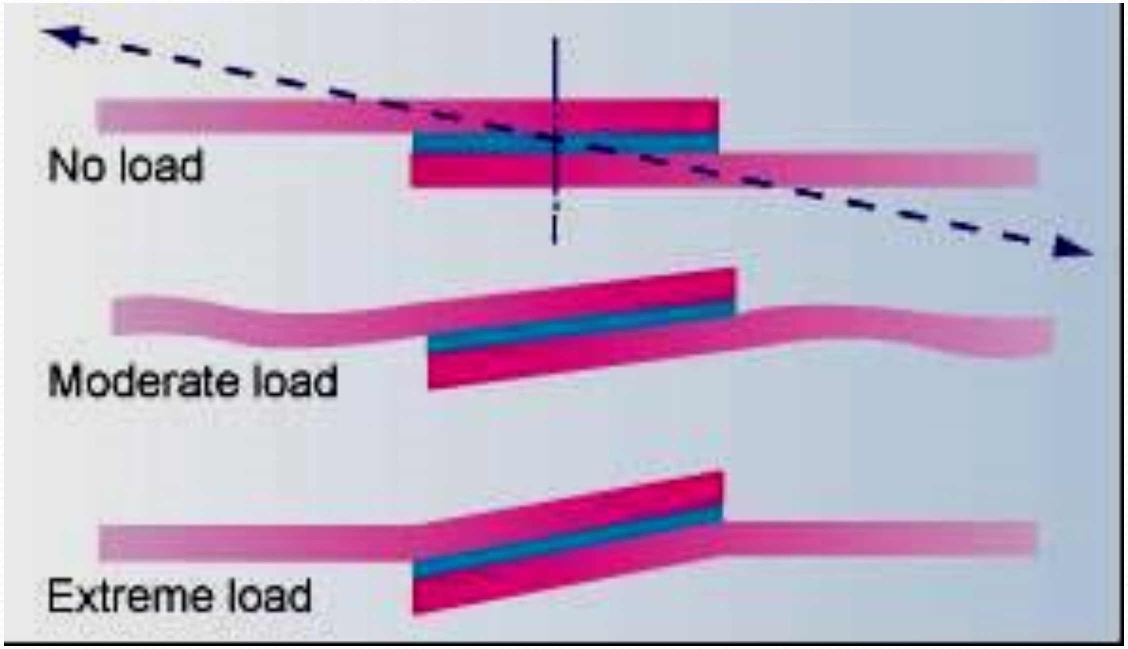
Recommended designs for rod and tube joints: (a) round bars and (b) cylinders or tubes



Types of angle joints and methods of reducing cleavage (top). Reinforcement of bonded corner joints (bottom)



Why stress is not only a adhesive problem but also substrate…



Toughness (ductility) is essential to distribute loads and best adhesive-substrate relations