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# Galling

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*For the botanical concept, see bark-galling.*

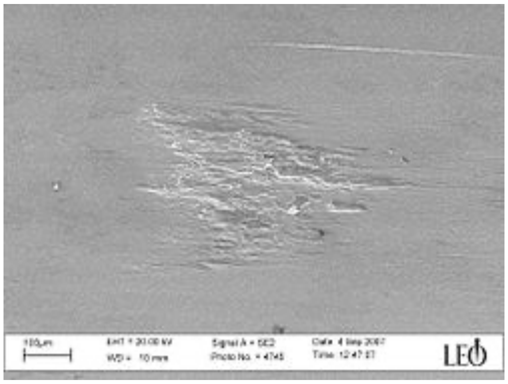

**Figure 1** An electron microscope image shows transferred sheet-material accumulated on a tool surface during sliding contact under controlled laboratory conditions. The outgrowth of material or localized, roughening and creation of protrusions on the tool surface is commonly referred to as a lump.

**Galling** usually refers to the adhesive wear and transfer of material between metallic surfaces in relative converging contact during sheet metal forming and other industrial operations.

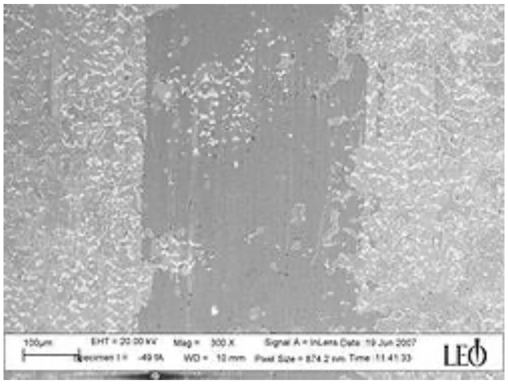

**Figure 2** The damage on the metal sheet, wear mode, or characteristic pattern shows no breakthrough of the oxide surface layer, which indicates a small amount of adhesive material transfer and a flattening damage of the sheet's surface. This is the first stage of material transfer and galling build-up.

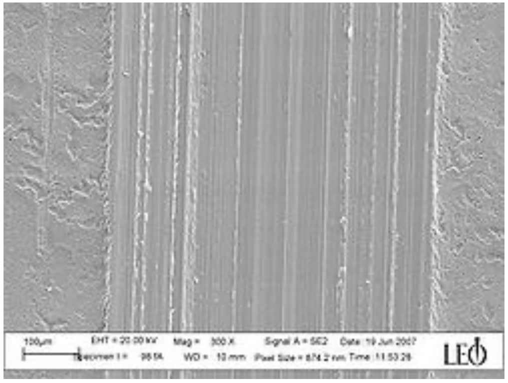

**Figure 3** The damage on the metal sheet or characteristic pattern illustrates continuous lines or stripes, indicating a breakthrough of the oxide surface layer. This type of contact can, in different proportions, be found simultaneously with the pattern found in Figure 4. Both characteristic patterns found in figure 3 and 4 arise as a consequence and are sequential to the pattern in figure 2.

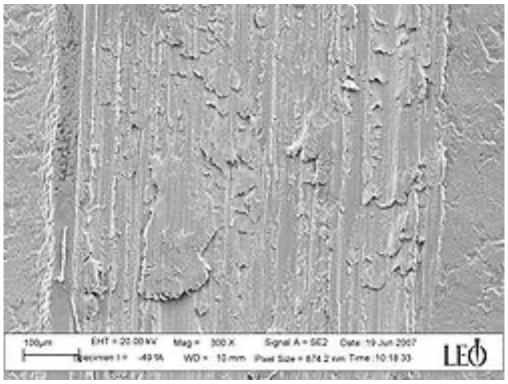

**Figure 4** The damage on the metal sheet or characteristic pattern illustrates an "uneven surface", a change in the sheet material's plastic behaviour and involves a larger deformed volume compared to flattening of the surface oxides seen in figure 2. This type of contact is associated and usually found in different proportions simultaneously with the pattern in figure 3.

**Galling** usually refers to the adhesive wear and transfer of material between metallic surfaces in relative converging contact during sheet metal forming and other industrial operations.

In engineering science and in other technical aspects, the term galling is widespread. The influence of acceleration in the contact zone between materials have been mathematically described and correlated to the exhibited friction mechanism found in the tracks during empiric observations of the galling phenomenon, (see figures 1,2,3 and 4). Due to problems with previous incompatible definitions and test methods, better means of measurements in coordination with greater understanding of the involved frictional mechanisms, have led to the attempt to standardize or redefine the term galling to enable a more generalized use. ASTM International has formulated and established a common definition for the technical aspect of the galling phenomenon in the ASTM G40 standard: "Galling is a form of surface damage arising between sliding solids, distinguished by microscopic, usually localized, roughening and creation of protrusions, (i.e. lumps, see figure 1), above the original surface".[1]

# Contents

[hide]

# [edit] Mechanism

When two metallic surfaces are pressed against each other the initial interaction and the mating points are the asperities or high points found on each surface. An asperity may penetrate the opposing surface if there is a converging contact and relative movement. The contact between the surfaces, initiates friction or plastic deformation and induces pressure and energy in a small area or volume called the contact zone.

The elevation in pressure increases the energy density and heat level within the deformed volume. This leads to greater adhesion between the surfaces which initiate material transfer, galling build-up, lump growth and creation of protrusions above the original surface. An example of accumulated transferred material or “lump growth” on a tool surface can be seen in figure 1. The initial asperity/asperity contact and surface damage on the opposing sheet-metal surface can be seen in figure 2.

If the lump (or protrusion of transferred material to one surface) grows to a height of several microns, it may penetrate the opposing surface oxide layer and cause damage to the underlying bulk material. Damage in the bulk material is a prerequisite for plastic flow that is found in the deformed volume which surrounds the lump. The geometry and the nominal sliding velocity of the lump defines how the flowing material will be transported, accelerated and decelerated around the lump. This torrent or material flow is critical when defining the contact pressure, energy density and developed temperature during sliding. The mathematical function describing acceleration and deceleration of flowing material is thereby defined by the geometrical constraints, deduced or given by the lump's surface contour. The contact damage from deformation of bulk material is seen in figure 3.

If the right conditions are met, such as geometric constraints of the lump that cause less energy transfer away from the contact zone than what is added by movement and plastic deformation, an accumulation of energy can cause a clear change in the sheet materials contact and plastic behaviour; generally this increases adhesion and the friction force needed for further advancement. The sheet damage from this type of high energy contact can be seen in figure 4.

In dynamic contact and sliding friction, increased compressive stress is proportionally equal to a rise in potential energy and temperature within the contact zone or "the system of the mechanics". The reasons for accumulation of energy during sliding can be the lesser loss of energy away from the contact zone due to a small surface area on the system boundary and low heat conductivity. Another reason is the amount of energy that is continuously forced into the system, which is a product of the acceleration of mass and developed pressure. In cooperation these mechanism allows a constant accumulation of energy and increased energy density and temperature in the contact zone during sliding.

The process and contact found in figure 4 can be compared to cold welding or friction welding[*citation needed*], because cold welding is not truly cold and the fusing points exhibit an increase in temperature and energy density derived from applied pressure and plastic deformation in the contact zone.

## [edit] Incidence and location

Galling or adhesive wear is often found between metallic surfaces where direct contact and relative motion have occurred. Sheet metal forming, thread manufacturing and other industrial operations may include made parts of stainless steel, aluminium and titanium[2] that are particularly susceptible to galling.

In metalworking that involves cutting (primarily turning and milling), galling is often used to describe a wear phenomenon which occurs when cutting soft metal. The work material is transferred to the cutter and develops a "lump". The developed lump changes the contact behavior between the two surfaces, which usually increases adhesion and resistance to further advancement and, due to created vibrations, can be heard as a distinct sound. An example of a change in material behavior can be seen in figure 4.

Galling often occurs with aluminium compounds and is a common cause of tool breakdown. Aluminium is a ductile metal, which means it possesses the ability for plastic flow with relative ease, which presupposes a relatively consistent and large plastic zone. In comparison, brittle fractures exhibit a momentary and unstable plastic zone around the cutter, which gives a discontinuous fracture mechanism that deters the accumulation of heat.

High ductility and flowing material can be considered a general prerequisite for excessive material transfer and galling build-up because frictional heating is closely linked to the constitution (physique) of plastic zones around penetrating objects and, as mentioned, brittle fractures seldom generate a great amount of heat.

Galling can occur even at relatively low loads and velocities because it is the real local pressure or energy density in the system that induces a phase transition, which often leads to an increase in material transfer and higher friction.

## [edit] Prevention

Adhesive wear and material transfer from one surface to another during sliding, so called galling, occur for a number of different materials and frictional systems. Generally there are two major frictional systems which effect adhesive wear or galling. In terms of prevention, they work in dissimilar ways and set different demands on the surface structure, alloys and crystal matrix used in the materials. The two frictional systems are:

- Solid surface contact (unlubricated conditions)
- Lubricated contact

*In solid surface contact* or unlubricated conditions, the initial contact is characterised by interaction between asperities and the exhibition of two different sorts of attraction. Cohesive surface energy or chemical attraction between atoms or molecules connect and adhere the two surfaces together, notably even if they are separated by a measurable distance. Direct contact and plastic deformation generates another type of attraction through the constitution of a plastic zone with flowing material where induced energy, pressure and temperature allow bonding between the surfaces on a much larger scale than cohesive surface energy.

In metallic compounds and sheet metal forming, the asperities are usually oxides and the plastic deformation mostly consists of brittle fracture, which presupposes a very small plastic zone. The accumulation of energy and temperature is low due to the discontinuity in the fracture mechanism. However, during the initial asperity/asperity contact, wear debris or bits and pieces from the asperities adhere to the opposing surface, creating microscopic, usually localized, roughening and creation of protrusions (in effect lumps) above the original surface. The transferred wear debris and created lumps penetrate the opposing oxide surface layer and cause damage to the underlying bulk material, allowing continuous plastic deformation, plastic flow, and accumulation of energy and temperature. With regard to the previously defined difference between the initial two types of attraction in "solid surface contact" or unlubricated conditions, the prevention of adhesive material transfer is accomplished by the following or similar approaches:

- Less cohesive or chemical attraction between surface atoms or molecules.

- Avoiding continuous plastic deformation and plastic flow, for example through a thicker oxide layer on the subject material in sheet metal forming (SMF).
- Coatings deposited on the SMF work tool, such as chemical vapor deposition (CVD) or physical vapor deposition (PVD) and titanium nitride (TiN) or diamond-like carbon coatings exhibit low chemical reactivity even in high energy frictional contact, where the subject material's protective oxide layer is breached, and the frictional contact is distinguished by continuous plastic deformation and plastic flow.

*Lubricated contact* sets other demands on the materials surface structure, and the main issue is to withhold the protective lubrication thickness and avoid plastic deformation. This is important because plastic deformation raises the temperature of the oil or lubrication fluid and changes the viscosity. Any eventual material transfer or creation of protrusions above the original surface will also deteriorate the ability to withhold a protective lubrication thickness. A proper protective lubrication thickness can be withheld by the following:

- Surface cavities (or small holes) can create a favourable geometric situation for the oil to withhold a protective lubrication thickness in the contact zone.
- Cohesive forces on the surface can increase the chemical attraction between the surface and used lubrication and enhance the lubrication thickness.
- Oil additives may reduce the tendency for galling or adhesive wear.

## [edit] Clarification and limitations

Galling should not be confused with attraction between surfaces without involving plastic deformation. This type of attraction should only be compared with adhesive surface forces or surface energy theories. Different energy potentials at the surfaces can develop adhesive bonds or cohesive forces that may hold the two surfaces together, but surface energy and the cohesive force phenomenon is not the same as galling and only partly correlate. Because galling involves plastic deformation of at least one surface.

However, the present research generally lacks a clear distinction between energy derived from plastic deformation and the adjacent counterpart cohesive surface forces and chemical attraction between atoms or surface molecules. The latter is likely involved in the initial material transfer, as shown in figure 2, where only surface-oxide asperities are in contact. But it is hard to distinguish these adhesive forces from more severe attractions caused by accumulated energy and increased pressure from plastic deformation. Oxides are brittle and it is probable that most of the energy in the fracture mechanism is consumed in brittle fracture, but the created wear debris will instantaneously penetrate the opposing surface. This means that the transferred oxide material will instantly act as a penetrating body and the concentration of energy, pressure and frictional heating is immediate, and without this accumulation of energy, the tendency for material transfer will certainly decrease.

The formation and constitution (physique) of plastic zones around penetrating objects are arguably a prerequisite and the main factor for excessive material transfer, lump growth and galling build-up even in the initial contact process (see figure 2).