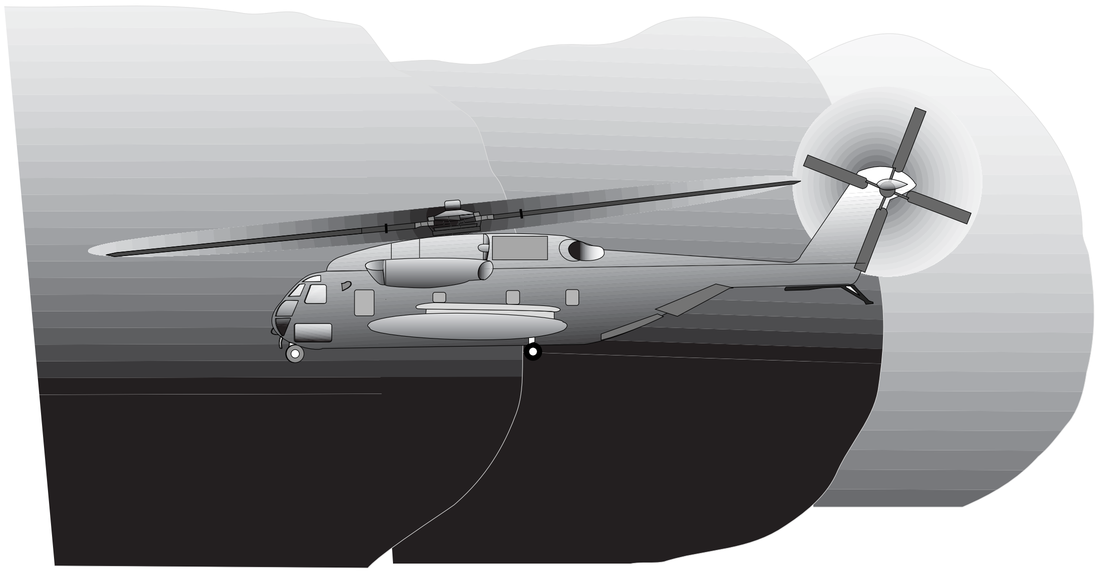
5.5 Erosion



The term erosion can be assigned different failure mechanisms:

■ **Particle erosion** (chapter 5.5.1.1) as an abrasive load through **movable particles**. These solid bodies act in a liquid or gas stream. They shatter and wear surfaces tribomechanically through sliding/cutting, rolling and impacting. This form of erosion will be additionally differentiated in the literature (Lit. 5.5.1-12) into:

- Abrasiv sliding wear (particle crenation),
- Purging wear (hydroabrasive wear).
- Blast wear/jet abrasion.

All these erosion mechanisms can take place in machines. Chapter 5.5.1 is focused at wear by **particles in the gasstream**. This can be expected in fluid flow engines and pipe line systems. Erosive acting particles can develop in the liquid itself. This is the case, if e.g., overheated organic liquids like fuels or oils develop microscopic **coke particles**. These deteriorate components of an oil system or fuel system. To these belong nozzles for injection and admeasurement as well as mechanical control units.

■ **Droplet impact/erosion** (chapter 5.5.1.2) is less known. It describes a mechanism, at which liquids even as droplets can act erosive (Ill. 5.5.1.2-1).

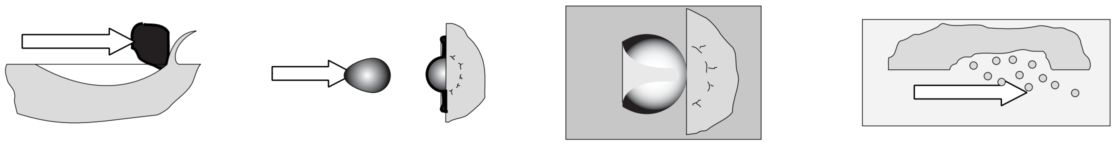
■ **Cavitation** (chapter 5.5.1.3) is caused by imploding **vapour bubbles** in the flowing liquid (Ill. 5.5.1.3-1). From it comes a danger of erosion for moving or static components in the liquid stream which is not to underestimate.

Air ingesting machines like **turbo machines and piston engines** are in the position to suck particles with the intake air flow. Also other erosive acting **machine own particles** like abrasion from wear processes e.g., rubbing of labyrinth seals) or spalling protection coatings (e.g., ceramic thermal barrier coatings) can cause erosion. These can occur everywhere, where an unfiltered air stream exists. An especially erosion loaded component of turbo engines is the **compressor** with its blading.

Primarily dust and rain drops (see chapter 5.5.1.1 and chapter 5.5.1.2) act erosive from outside of the engine. A critical erosion problem can especially be expected at **fiber reinforced materials with plastic/resin matrix**. Here suitable protection coatings are a requirement for the successful longtime use in series.

The erosion effect of ingested particles, usually drops with the cobered distance through a turbo engine. This is associated by the splintering of the particles during the first impact (Ill. 5.5.1.1-1).

5.5.1 Erosion Mechanisms.



The **erosion mechanisms** in an engine can be influenced bot, microscopically and macroscopically, in a characteristic manner by the locally **effective parameters**. For example, depending on the angle of attack of erosive particles, erosive wear can occur primarily through cutting or splintering mechanisms (Ill. 5.5.5.1.1-1).

The **damage symptoms** understandably depend on the many parameters of the erosion process. These include the particle size and type, impact speed (Ill. 5.5.1.1-4), impact angle (Ill. 5.5.1.1-3), number of particles (Ill. 5.5.1.1-5), and the duration of the particle influence. In addition, the extent of the damage is also dependent on the properties of the erosion-stressed part, such as **material properties** (strength, ductility, oxidation behavior, etc.), **surface topograph**y (size and geometry of roughness), and **macrogeometry** (such as the leading edge radius of blades), to name a few important factors.

It is easy to see that an erosion process is a **combination of extremely complex single processes** that must be understood.

The dominant erosion mechanism in engines is abrasion through impacting particles. This abrasion mechanism can occur in various ways, depending on the particle energy and the properties of the part surface and the amount of particles (Ill. 5.5.1.1-1). With **ductile materials** micro-level chip removal can be expected. Hard, **brittle materials** can suffer micro-level fatigue processes resulting nicks and disruptions, and brittle materials e.g., coatings can spontaneously splinter out. In this case a markedly **drop of dynamic fatigue strength** must be expected (Ill. 5.4.3.2-10).

Other types of wear in which the dominant wear mechanism is **surface disruption**, such as **rain erosion** (droplet impact, chapter 5.5.1.2) or **cavitation** (erosion in liquids due to vapor bubble implosion, chapter 5.5.1.3), are briefly covered here (Ill. 5.5.1.3-1). Another type of erosion that has not been recognized as being damaging until now should also be mentioned (referred to here as “fine erosion“). It is usually observed at the micro-level on the back sides of blades and lays bare the microstructure (especially in titanium alloys) in a manner similar to etching (sputter effect of the air molecules?). Remarkable damages don’t occur. However, a targeted roughness in form of a microstructuring (‘shark skin effect’) may trigger a problematic change over a long time.

With erosion processes in hot parts, additional mechanisms are involved that are based on the oxidation of blank metal surfaces (erosion surfaces) or on reactions with the base material or the oxide layers (such as sulfur particles in gypsum dust, see also chapter 5.6.2). These mechanisms can significantly increase the wear rate and damage, caused by otherwise relatively weak abrasive erosion processes.

Influences from Outside: Erosion: Mechanisms.

Ill. 5.5.1-1: *If erosion is understood as **surface wear** caused by the mechanical action of a media, then there are many **different mechanisms** which fit this definition (bottom diagram).*

*Erosion through solid particles is generally referred to as **blast/peening wear**. Other terms that are frequently found especially in older literature, but are not in DIN 50320, include **mineral wear, sand and dust erosion, and abrasive wear**. The material being eroded through the impact of hard particles is experienced slice/furrow-like **chip removal**. With hard materials, especially hard coatings on softer base material, the wear occurs primarily as **splintering** and/or **fatigue crack formation**, as well as the **breaking out of particles**. This type of erosion process occurs primarily on the aerodynamic surfaces of the compressor and turbine bladings. Abrasive wear does not occur solely through the air flow, but can also be caused by hard particles carried in liquids. A typical example is **coke particles** in an overheated fuel flow that can cause extensive erosion damage to the injection system.*

***Droplet impact** always occurs as an erosive load when droplets of liquid strike a surface at high speeds. If the liquid is rain, then it is referred to as **rain erosion** (chapter 5.5.1.2). This process creates shockwaves and deformations in the material which, in case this process is frequently repeated, lead to fatigue and breaking-out of the material. This type of wear can occur in rotor blades (compressor, turbine) propeller (e.g., halicopter, wind energy plant) and airframe (Ill. 5.5.1.2-0).*

***Rain erosion can be a serious problem for parts made from fiber-reinforced synthetics/plastics** (FRP).*

*With **cavitation**, the erosion process takes place in a flowing liquid (chapter 5.5.1.3).*

Cavitation damages have been observed at many machine elements.

*Cavitation has been recorded on **components of the fuel system** such as injection nozzles and regulators as well as on the pump gears of turbo pumps.*

*Cavitation has also been blamed for damages to **gear pumps** (Ill. 5.5.1.3-1) **and transmission gears** (Ill. 5.5.1.3-8) at low external pressure (easier vapor bubble formation due to the low air pressure). This can limit the design rotation speed of gear pumps..*

*In **sliding ring seals** and **friction bearings** cavitation can develop at the sliding surface and damge it (Ill. 5.5.1.3-7, and Ill. 5.5.1.3-11, Lit. 5.5.1-16).*

***Rain corrosion** can cause considerably heavier erosion damage than cavitation (top right diagram). The extreme **sensitivity of polycarbonate and glass to droplet impact** is especially conspicuous.*

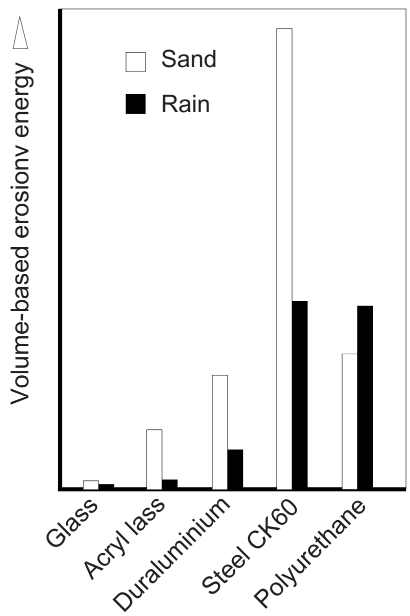
*In the same way that strong wind throws up sand, an extremely intense **gas flow**, especially in the rear compressor area, can cause particles to break free from soft coatings such as the abradable coatings in compressor casings (e.g. porous nickel-graphite thermal spray coatings). This process can be **self-increasing**, since these particles, in turn, have an erosive effect.*

*The top left diagram shows that materials can behave considerably differently during erosion through solid particles than they do during erosion through drops of liquid (Lit. 5.5.1-1 and Lit. 5.5.1-2). For example, it can be seen that soft, elastic, very ductile polyurethane has a high erosion resistance against sand and rain (compared with plexiglas or aluminum, etc.), which makes its use as a **protective coating against erosion on fiber reinforced plastic parts** understandable. The great resistance to rain erosion relative to the resistance to sand erosion cannot be observed in any other (harder) materials.*

Materials can behave differently when subjected to different erosion mechansims.

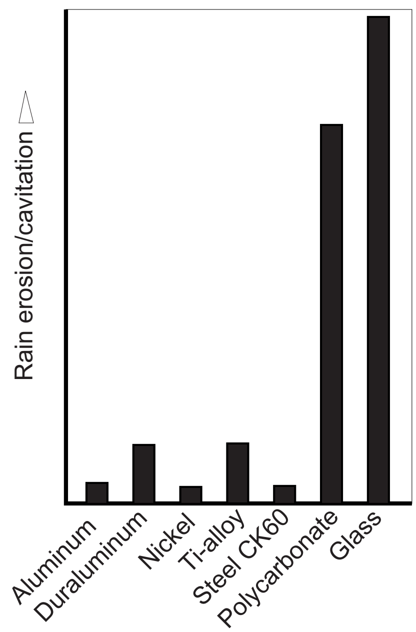
Comparison of the erosion strengths of various materials against sand and rain erosion under equal erosion energy

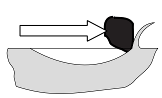
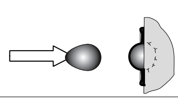
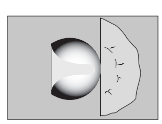
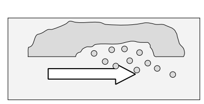
(Re: W.Kayser)



Relationship of the erosion rates of rain erosion and cavitation

(Re: H.Rieger)



Wear type.	Tribologic loads.		Mechanisms.	Examples of erosion loaded emgine parts.
Blasting wear - Glide plane wear - Angled blast wear - Colliding blast wear Sand and dust erosion Mineral wear Abrasive wear		Cutting process: Splintering of the surface zone. Fatigue crack initiation	Abrasion.	Compressor blades.
Droplet impact (Rain erosion)		Shock waves: Deformation and fatigue with crack initiation	Surface disruption, tribo-chemical reactions	Fan blades. Steam turbines (wet steam stages).
Cavitation Flow cavitation Vibration cavitation		Imploding vapor bubble creates shock waves: Deformations and fatigue with crack initiation.	Surface disruption, tribo-chemical reactions	Control unit parts Friction bearings Injection nozzles Fuel pumps
Erosion through a gas stream		Crumbling of brittle and porous coatings due to gas forces in the flow	Abrasion, surface disruption, tribo-chemical reactions	Spray coatings in housings and labyrinths
A combination of several wear types is possible.				

Ill. 5.5.1-1