CHAPTER 1

INTRODUCTION
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1.1 Definition[1]

The impact 'resistance' of a composite may refer to the ability of the composite to withstand a given blow without any damage (i.e., the resilience); the maximum force necessary to rupture or separate a composite structure, irrespective of the preceding level of damage (the impact strength); the amount of energy that is absorbed by a given mass of the composite (the crush resistance); or perhaps the level of damage that a composite can sustain during impact loading without suffering undue reduction to some primary structural function after the impact event (damage tolerance).

Impact resistance is one of the most important properties for a part designer to consider, and without question the most difficult to quantify. The impact resistance of a part, in many applications, is a critical measure of service life. More importantly these days, it involves the perplexing problem of product safety and reliability.

1.2 Impact theory

1.2.1 Some basic definitions pertaining to impact[2]

Penetration: Penetration may be defined as the entrance of a missile into a target without completing its passage through the body. This generally results in the embodiment of the striker and formation of a crater.

Perforation: Perforation is the complete piercing of a target by the projectile. Such processes occur in a time frame of several to several
Ricochet: If the projectile rebounds from the impacted surface or penetrates along a curved trajectory emerging through the impacted surface with a reduced velocity, the process is termed ricochet.

1.2.2 Classification of impact phenomenon[2]

The study of impact phenomena involves a variety of classical disciplines:

Low velocity Regime(<250m/s): In the low velocity regime many problems fall in the area of structural dynamics. Local indentations or penetrations are strongly coupled to the overall deformation of the structure. Typically, loading and response times are in the millisecond regime.

Medium velocity regime(0.5-2km/s): As the striking velocity increases the response of the structure becomes secondary to the behaviour of the material within a small zone (typically 2-3 projectile diameters) of the impact area. A wave description of the phenomena is appropriate and the influences of velocity, geometry, material constitution, strain rate, localized plastic flow and failure are manifest at various stages of the impact process. Typically, loading and reaction times are on the order of microseconds.

High velocity regime(>2 km/s): Still further increases in impact velocity result in localized pressures that exceed the strength of the material by an order of magnitude. In effect, the colliding solids can be treated as fluids in the early stages of impact.
Ultra high velocities (>12km/s): Here energy deposition occurs at such a high rate that an explosive vaporisation of the colliding materials results.

Other than the above, impact phenomena can be characterized in a number of ways: according to the impact angle, the geometric and material characteristics of the target or projectile, or striking velocity etc.,

1.2.3 Different types of loading[3]

The classes of loads that are generally applied to any material/structural systems are:

i. Static or dead loading
ii. Quasi-static loads applied during material and structural testing
iii. Dynamic loads, including Vibratory, random and transient
iv. Steady state
v. Impact /impulsive
vi. Hydrodynamic loads

Static refers to very slow, long term load application while quasi-static is usually associated with generating data from laboratory test equipment such as servo-hydraulic or screw driven test equipment. The loading times associated with these tests are considered to be long enough in duration as compared with the material response such that the internal equilibrium within the material is maintained throughout the loading
process. As the loading time is shortened, material/structural inertial effects becomes important and the loading becomes dynamic.

The principle types of dynamic loading in which the system responds as a material can be broadly classified as (1) Vibratory and (2) impact/impulsive.

For vibratory loading, the type of response obtained is directly linked to the applied force. If the forcing function is repetitive and continuous, then the response can be considered as steady state, that is, to a degree, independent of the exact time of application of the forcing function. Sinusoidal forcing functions are often used for representing this type of vibratory response. When the forcing function is non-repetitive and of finite time duration, the material response is considered transient. Once the transient phase has passed, the response becomes steady state. The system response in the transient stage, however may result in higher stresses and displacements when compared to the response in the time regime following cessation of the load. Random vibration effects occur when the instantaneous magnitude of the load is unspecified for any instant of time and the instantaneous magnitudes are specified by probability distribution functions.

Impact loads are short term loads created by the interaction/collision of two solid bodies, one of which may be at rest. Impulse loads are short time loads produced by striking objects, one of which is not characterized as solid. For extremely short duration loads, in which the material no longer retains rigidity, the material is said to be exposed to shock loading.

Normal impact is considered to be the most unfavourable dynamic
loading condition. For the case of impact loading, the response of a material/structural dynamic event can be divided into two general classifications – that of primary and secondary response. The former is associated with effects occurring in the immediate vicinity of the impacting bodies, while the second occurs after the initial impact time and can occur in the far field. The first is governed by stress waves and rate effects, while the second is associated with a response governed by the constitutive equations of the material/structure.

Finally, in summary, the two principle effects associated with the response to impact loading can be identified as contributions of the inertia effects of the impacting bodies and the associated wave propagation phenomena, and changes occurring in the mechanical properties of the system as affected by strain rate effects.

Table 1.1 shows the rate effects and dynamic considerations for the above different types of loading.
Table 1.1: Rate effects and dynamic considerations for different types of loading [3]

<table>
<thead>
<tr>
<th>Type of loading</th>
<th>Characteristic time (s)</th>
<th>Strain rate (s⁻¹)</th>
<th>Response</th>
<th>Dynamic considerations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant load or Stress machine</td>
<td>10⁶ - 10⁴</td>
<td>10⁻⁸-10⁻⁶</td>
<td>Static</td>
<td>Inertia forces neglected</td>
</tr>
<tr>
<td>Hydraulic or Screw machine</td>
<td>10² - 10⁰</td>
<td>10⁻⁴-10⁻²</td>
<td>Quasi-static</td>
<td>Inertia forces neglected</td>
</tr>
<tr>
<td>Mechanical machines</td>
<td>10²</td>
<td>10⁰</td>
<td>Quasi-static</td>
<td>Inertia forces important</td>
</tr>
<tr>
<td>Pneumatic/Mechanical/explosive impact</td>
<td>10⁻⁴</td>
<td>10²</td>
<td>Dynamic</td>
<td>Inertia forces important</td>
</tr>
<tr>
<td>Light gas gun or explosive driven plate impact</td>
<td>10⁶ - 10⁻⁸</td>
<td>10²-10⁶</td>
<td>Hydrodynamic</td>
<td>Inertia forces important</td>
</tr>
</tbody>
</table>

1.2.4 Material or structural response during impact loading[2]

The response of materials and structures to impact loading is quite complex. Practical impact problems involve strikers and targets with finite boundaries which exert considerable influence on their behaviour. As the intensity of the applied loading increases, the material is driven into the plastic range. The behaviour involves large deformations, heating and often failure of the colliding bodies through a variety of mechanisms. With still further increase in loading intensity, pressures are generated that
exceed the strength of the colliding bodies by several orders of magnitude, which in effect, behave hydrodynamically.

For low intensity excitations, both the geometry of the entire structure as well as the nature of the material from which it is made, play a major role in resisting external forces. As loading intensity increases, the response tends to become highly localised and is more affected by the constitution of the material in the vicinity of load application than the geometry of the total structure. A description of the phenomena in terms of elastic, plastic and shock wave propagation becomes appropriate.

Elastic theory for isotropic solids indicates propagation of 2 types of waves. Dilational (longitudinal) waves are those in which the particle motion induced by the disturbance is normal to the wave front. Distortional (transverse or shear) waves are those wherein material particles move in a plane at right angles to that in which the wave front propagates. Under proper loading conditions torsional and flexural waves may also be generated.

In impact situations, there is the normal impingement of a strong compressive pulse on a free surface. The pulse is reflected as a tensile wave and if its magnitude is greater than the tensile strength of the material, fractures occur causing material separation. If after fracture, the magnitude of the stress pulse still exceeds the material's tensile strength, multiple fractures can occur. As the intensity of the applied load increases, the material is driven beyond its elastic limit and becomes plastic. 2 waves now propagate in the solid, an elastic wave (or precursor) followed by a much slower but more intense plastic wave. If the characteristics of the medium are such that the velocity of propagation of
large disturbances is greater than the propagation velocity of smaller ones, the stress pulse develops a steeper and steeper front on passing through the medium, and the thickness of this front is ultimately determined by the molecular constitution of the medium.

If the intensity of the loading is so great or its duration so short that the material no longer possesses rigidity, it will behave as though it had the properties of a fluid. Transverse (shear) waves cannot exist within the body and only a longitudinal wave will be propagated with a velocity \( c_B^2 = K/\rho \) where \( K \) is the bulk modulus and \( \rho \) the density. In this shock wave regime, extremely high pressures are generated which can lead to changes in density of materials.

When a material is stressed with a suddenly applied load, the deformation and stresses are not immediately transmitted to all parts of the body, remote portions remaining undisturbed for some time. Deformations and stresses progress through the material in the form of one or more stress disturbances which travel at a finite velocity from the area of application of the load, this velocity being a characteristic of the material. Such a suddenly applied, or impulsive, load may be produced by a sharp mechanical blow, a detonating explosive, or impact of a high velocity projectile. Regardless of the method of application, the consequent stress disturbances have identical properties.

In an elementary case, 2 types of stress pulses generated by an impulsive load are considered. The first, the longitudinal wave, is also called a dilational, irrotational or primary(P) wave, the terms being synonymous. In a longitudinal pulse, the particle motion is parallel to the direction of propagation of the pulse and the strain is pure dilational. In a
transverse wave, otherwise called a distortional, rotational, secondary or shear wave, the particle motion is normal to the direction of propagation of the pulse and the strain is a shearing strain.

Representation of the pulse can be accomplished in any one of the following ways
Stress versus time
Particle velocity versus time
Stress versus distance
Particle velocity versus distance
Two velocities must be considered: the velocity of propagation \( c \) of the disturbance and the particle velocity \( v \), the velocity with which a point in the material moves as the disturbance moves across it.

\[ \sigma \]

\[ \varepsilon \]

**Figure 1.1: Characteristic uniaxial stress strain curves[2]**

A complete description of the dynamics of impacting solids would demand that account be taken of the geometry of the interacting bodies, elastic, plastic and shock wave propagation, hydrodynamic flow, finite strains and deformations, work hardening, thermal and frictional effects, and the initiation and propagation of failure in the colliding materials.
Table 1.2 gives the impact response effects in materials subjected to different striking velocities.

1.2.5 Target classification[2]

Targets are best classified as

*Semiinfinite* : If there is no influence of the distal boundary on the penetration process

*Thick* : If there is influence of the distal boundary only after substantial travel of the projectile into the targets

*Intermediate* : If the rear surface exerts considerable influence on the deformation process during nearly all of the penetrator motion

*Thin* : If stress and deformation gradients throughout its thickness do not exist.
<table>
<thead>
<tr>
<th>Strain rate</th>
<th>Vs (striking velocity)</th>
<th>Effect</th>
<th>Method of loading</th>
</tr>
</thead>
<tbody>
<tr>
<td>$10^8$</td>
<td>&gt;12kms$^{-1}$</td>
<td>Explosive impact colliding solids vaporised</td>
<td>-</td>
</tr>
<tr>
<td>$10^7$</td>
<td>3-12kms$^{-1}$</td>
<td>Hydrodynamic – material compressibility not ignorable</td>
<td>Explosive acceleration</td>
</tr>
<tr>
<td>$10^5$</td>
<td>1-3kms$^{-1}$</td>
<td>Fluid behaviour in materials; pressures approach or exceed material strength: density a dominant parameter</td>
<td>Powder guns, gas guns</td>
</tr>
<tr>
<td>$10^4$</td>
<td>500-1000ms$^{-1}$</td>
<td>Viscous – material strength still significant</td>
<td>Powder guns</td>
</tr>
<tr>
<td>$10^2$</td>
<td>50-500ms$^{-1}$</td>
<td>Primarily plastic</td>
<td>Mechanical devices, compressed air guns</td>
</tr>
<tr>
<td>$10^0$</td>
<td>&lt;50ms$^{-1}$</td>
<td>Primarily elastic, some local plasticity</td>
<td>Mechanical devices, compressed air guns</td>
</tr>
</tbody>
</table>
1.3 Failure phenomena in impacted materials[2]

Impacted materials may fail in a variety of ways. The actual mechanisms will depend on such variables as material properties, impact velocity, projectile shape, method of target support and relative dimensions of projectile and target.

**Spalling**: This is a tensile failure as a result of the reflection of the initial compressive wave from the rear surface of a finite thickness plate, is a common place occurrence under explosive and intense impact loads, especially for materials stronger in compression than in tension.

**Scabbing**: This is similar in appearance to spalling, but here fracture is produced by larger deformations and its surface is determined by local inhomogeneities and anisotropies. Fracture, as a result of an initial stress wave exceeding a material’s ultimate strength, can occur in weak, low density targets while radial cracking is common in materials such as ceramics where the tensile strength is considerably lower than the compressive strength.

**Plugging**: Plugging failure is quite sensitive to the impact angle and nose shape of the projectile. The significance of adiabatic shear failure is more clearly seen for penetration by projectiles with sharp nose configurations.

**Petaling**: Petaling is produced by high radial and circumferential tensile stresses after passage of the initial stress wave. The intense stress fields occur near the tip of the projectile. Bending moments created by the forward motion of the plate material pushed by the striker cause the characteristic deformation pattern. It is most frequently observed in thin
plates struck by ogival or conical bullets at relatively low impact velocities or by blunt projectiles near the ballistic limit. Petaling is accompanied by large plastic flows and permanent flexure.

Figure 1.2: Schematic representation of failure in impacted materials

1.4 Damage in composite materials due to low velocity impact

For polymeric composites[4], low velocity transverse impact has been identified to be one of the most common forms of loading event (typically occurs during servicing the aircraft) that results in delamination (failure mode) which can adversely affect the structural integrity of the composite structure. The evaluation of the effects of such impacts, as well as the distribution of the stress waves due to impact as a function of time and space is highly complex due to the heterogeneous and anisotropic nature of the composite material and is further complicated by the loading rate. Another
important factor that affects the impact events are the boundary conditions which may vary from rigidly fixed to free to simply supported. The structural capacity is assessed typically by measuring the residual properties that are of significant design interest. For laminated composites, compression strength is considered to be a critical measure as it is strongly influenced by ply delaminations and is quite relevant in structural design.

Although advanced composites have been accepted as engineering materials and the design/analysis techniques for the response of composite materials and structures to static loads are well established, no comparable techniques are available for design of advanced composites against foreign object impact. Although the response of composite materials to particle or foreign body impact could be studied using empirical or semi-empirical approaches, this appears undesirable because of the large and costly efforts that would be required to cover the various combinations of constituent materials, lay-ups, stacking sequences and constructions. Therefore, when designing for impact response, it appears desirable to have a criterion for determining how the various properties of the target and the impact parameters influence target damage.

1.5 About impact testing

1.5.1 Background[1]

In standard testing, such as tensile and flexural testing, the material absorbs energy slowly. In real life, materials often absorb applied forces very quickly: falling objects, blows, collisions, drops, etc. The purpose of impact testing is to simulate these conditions.
Impact testing is testing an object’s ability to resist high-rate loading. It is usually thought of as object striking another object at a relatively high speed. In this context, what is required to be determined is that:

1) The impact energies the part can be expected to see in its lifetime
2) The type of impact that will deliver that energy, and then
3) Select a material that will resist such assaults over the projected life span.

Molded-in stresses, polymer orientation, weak spots (e.g. weld lines or gate areas), and part geometry will affect impact performance.

Most real world impacts are biaxial rather than unidirectional. Plastics, being anisotropic, cooperates by divulging the easiest route to failure. Further complication is offered by the choice of failure modes: ductile or brittle. Brittle materials take little energy to start a crack, little more to propagate it to a shattering climax. Other materials possess ductility to varying degrees. Highly ductile materials fail by puncture in drop weight testing, and require a high energy load to initiate and propagate the crack. Many materials are capable of either ductile or brittle failure, depending upon the type of test and rate and temperature conditions. They possess a ductile/brittle transition that actually shifts according to these variables. For example, some plastic food containers are fine when dropped onto the floor at room temperature but a frozen one can crack when dropped.

An engineer needs to attach a value to the energy transferred from one object to the other during an impact test. The first attempts at obtaining this value were done by means of a swing pendulum. A pendulum of a known weight is hoisted to a known height on the opposite side of a pivot point. By
calculating the acceleration due to gravity (9.8 m/sec\(^2\)), the engineer knows that the weight falling from a set height will contain a certain amount of impact energy at the bottom of the swing.

By clamping or supporting a specimen on the bottom, the sample can be released to strike and break the specimen. The pendulum will continue to swing up after the break event to a height somewhat lower than that of a free swing. The engineer can use this lower final height point to calculate the energy that was lost in breaking the specimen. Many pendulum machines will incorporate a pointer and energy reading device so that calculation is unnecessary.

A second method was to drop a weight in a vertical direction, with a tube or rails to guide it during the "free fall". Once again, with the height and weight known, impact energy can be calculated. In the early days, there was no way to measure impact velocity, so engineers had to assume no friction in the guide mechanism. Since the falling weight either stopped dead on the test specimen, or destroyed it completely in passing through, the only results that could be obtained were of a pass/fail nature.

There is a simple piece of test equipment that is still in use today that is referred to as a Gardner tester. Gardner was originally the manufacturer's name and the test method eventually also became known as a "Gardner test" (ASTM D-3029, D-5420). It consists of a tube with a weight that slides inside it. The weight is dropped from increasing heights until a "failure" is discovered (everyone has a different definition of what "failure" means). At that point, the operator begins fiddling around, raising and lowering the drop height until 50% of the specimens "fail". Any drop weight style tester used in this manner is employing the Bruceton Stairstep Method to determine
impact damage values. Disadvantages are that a large number of specimens (50-100) may be needed to determine what the correct drop height should be and it is very subjective since it requires an operator’s judgment call on failure. Plus for best resolution, the operator has to vary the height by the tiniest increment possible – almost impossible unless he wants to run even more tests. Sometimes, the operator may keep running and never find the mean drop height! In addition, when one changes the drop height, the impact velocity is changed and therefore subjects the material to a different strain rate – many materials are strain rate sensitive (behave differently at different strain rates).

Instrumented impact testing eliminates many of the Gardner test’s inherent flaws and problems with Gardner. The early methods of impact testing were useful but lacked important information about what was happening to the test specimen during the impact event. In the early 1950s and 1960s, scientists started attaching strain gages to the test specimen or impact device. But this was rather complicated with oscilloscopes, laser triggering setups, and photographing the scope display. It usually raised more questions than they answered.

ASTM and ISO are the main bodies in charge of all types of testing. In the field of impact testing, they are in charge of writing and updating all specifications with the test parameters used by engineers to evaluate materials. These test parameters include specimen dimensions and geometry, impact velocity, and what information to report.
1.5.2 Impact testing specifications

There are a number of organizations that regulate various test methods for impact testing. The most common are:

- ANSI (American National Standards Institute)
- ASTM
- BOEING (Boeing Aircraft)
- BSI (British Standards Institute)
- DIN (German)
- ISO
- FORD (Ford Motor Co.)
- GM (General Motors Corp.)
- JIS (Japanese Industrial Standard)
- NASA
- NRA (National Rifle Association)

Within the USA, the most common are ASTM, ISO, and GM. The auto industry is moving to ISO. ANSI does not write test specifications any more and now refers to an ASTM method.

1.5.3 Impact test methods[3](figure 1.3)

1. Punch tests
2. Izod, charpy tests
3. Drop weight tests
4. Hydraulic/pneumatic machines
5. Hopkinson pressure bar
6. Flyer plate

**Cantilever Beam (IZOD)**

**Three Point Bend (CHARPY)**

**Penetration**

**Single Impact Rebound**

**Energy Absorption**

**Component Evaluation**

*Fig 1.3: Different facets of impact testing*
1.5.3.1 A brief note on punch tests, Izod Charpy tests, Hopkinson pressure bar and flyer plate tests

The punch test (Loading rates: $10^{-7}$ to 10 m/s) is a low speed test and is generally used for obtaining data on the shear strength of resin matrices and composites. This type of test is recognised as a way of testing materials and structure for their resistance to penetration and/or perforation under high velocity projectile impacts the types of which occur in armament penetration problems, containment of fragments generated in turbo transportation engine dis-integrations etc., For this type of test, the specimen is designed so that it can be rigidly clamped to a stationary fixture: auxiliary deflections are not permitted. The loading is applied by a device capable of delivering a constant speed loading ram. Data can be obtained on punch load Vs punch speed, force-time histories, type of fracture and damage expected.

The Izod/Charpy tests (Loading rates: 0.005 to 1000mm/s) have been used for many years to determine the energy absorption, notch sensitivity, fracture toughness and fracture behaviour of monolithic materials. For these tests, an impact load is produced by swinging a weight from a fixed height into a notched specimen. The notch is introduced into the material specimen in order to produce a stress concentration and thus promote failure in the case of ductile materials. A typical Charpy impact specimen consists of a rectangular cross-section beam notched at the beam mid-point, simply supported and struck by the impacting weight at this point.

Izod specimen is a cantilever beam notched on the tension side of the specimen to ensure that fracture occurs under the impact load. During
charpy or izod tests, the energy lost by the impactor can be expressed as the sum of various energies such as energy required to initiate fracture of the specimen, energy required to propagate fracture across the specimen and the energy required to propel the broken specimen. For composites which are inherently brittle, the complicated fracture process may involve other energy absorbing processes. For tough, ductile or fibre filled materials, the most important factors are the energy required to propagate fracture through the specimen, vibration of the impactor, and friction at the impact point.

Hydraulic/pneumatic tests (Loading rate: 1 to 50m/s) have been used to obtain data on composite strain rate sensitivity, failure modes, dynamic material properties and constitutive equation modeling. Tests of this type are useful for controlled strain-rate testing in the medium strain rate range. Some of the interesting observations made concerning composite failure include the fact that the number of fibre breaks at high rates is higher than that at low rates, and that the strain rate corresponding to the ultimate load is dependent on the ultimate load of the individual glass fibres.

Hopkinson pressure bar test (Loading rate: $10^2$ to $10^4$/s) is one of the most widely used for evaluating high strain rate effects in materials. This type of test procedure has been used to examine the dynamic response of materials in various modes of testing. Some of the important data obtained by using pressure bar testing include strain-rate sensitivity, material properties, dynamic yield stress, damage propagation and fracture/failure mechanisms. The original apparatus consists of a bar several feet long and approximately one inch in diameter suspended by threads, with an attached end piece that acted as a momentum trap. The end piece was held onto the
main bar by magnetic attraction. A bullet was then fired to impact axially the end of the main bar opposite from the momentum trap. When the compressive wave, reflected as a tensile wave from the free end of the momentum trap, reached the interface between the two bars, the tensile wave broke the weak magnetic attachment and permitted the end piece, which now contained all the momentum, to fly off and leave the main bar in place. The end piece swung upward, supported by threads, and the magnitude of its swing was related to the amount of momentum trapped in at the beginning of the swing. The hopkinson pressure bar systems has different set-ups for tensile, compression, flexure and shear.

Flyer plate tests (Loading rate $10^4 - 10^6$/s) have been introduced to study material behaviour and failure modes at high stresses (>1k bar loading) and short time duration loads (<10^-6 s). For such tests the associated strain rates are $10^4$ per second or higher and represent the highest strain rate for one-dimensional strain rate. The technique used generally involves the impact of a flyer plate of one material projected at a target of a similar or different material. The most popular launch devices for such systems include gas guns, explosive discharge, exploding foil and magnetic driven propulsive devices. Each of these launch devices can be considered as inputs for obtaining certain types of data. For example, the gas gun launch system is found useful for establishing constitutive modeling while the exploding foil technique produces higher velocities and is useful in establishing failure data.
1.5.3.2 Drop weight tests: (*Loading rate: 1-10 m/s*)

Drop weight tests have been used instead of charpy/izod tests to obtain information of material energy absorption, fracture toughness, failure mechanisms, strength reduction and notch sensitivity. The apparatus consists of a tower frame with a weight capable of being raised with little friction in the vertical direction. The drop weight can incorporate different indentor tips (tups) and the drop weight itself can be varied by adding additional weights. The velocity of the striking drop weight can be measured by means of disruption of photodiode light sources placed at a fixed distance from one another.

In most dictionaries, a tup is defined as a "ram" or "heavy metal end of a pendulum". This can be confusing because here a tup is an instrumented "load cell", another industry term. The actual "ram" or "striker" that impacts the test piece is called a "tup insert".

While a load cell used for weighing trucks or packages will have a full scale output of 20 - 30 milli-volts, an impactor tup will have a full scale output of ~ 500 millivolts. So, the load cell will show little change in output with a large change in load while the tup will show a large output with a small change in load. This is essential in the impact environment, where tests last only a few milliseconds.

When a tup strikes a test specimen, the force generated by the impact is transferred through the body of the tup. The force causes the tup to deflect. In the case of a drop-weight tup, the force causes the tup to become compressed. If designed properly, the change in overall length of the compressed tup can be made to occur in one particular place. That place is
called the gage (or "gauge") pocket.

In the gage pocket area, semiconductor strain gages are bonded to the surface of the tup. Strain gages are basically resistors that change their resistance according to the amount that they are stretched or compressed. During impact, as the tup deflects the pocket, the gages change their resistance. Since a fixed input voltage (called excitation voltage) is applied across the gages, the change on resistance causes a change in the output voltage.

The gages are typically arranged in an instrumentation, or Wheatstone bridge, configuration. This configuration is important since it can be balanced so that with a zero load on the system, the output is zero or within an acceptable range. Older tups used a 4-gage bridge, while newer tups use an 8-gage version. In the 8 gage version, the gages are arranged in pairs, with one gage oriented to "see" the force while the other is a reference or "Poisson" gage. The reference gage will compensate the circuit for any strain that occurs in the plane perpendicular to the axis of the active gages. This is important because gages "see" all forces, but are unable to sort them out by direction.

Most of the efforts at characterizing and understanding the impact properties of composite materials have been directed towards the use of charpy and izod type tests. These tests, especially their instrumented versions are easy to perform; but it is difficult to relate the results to impact damage of composites.
There are serious fundamental difficulties associated with the observed scatter and variability in data; these arise because there are unknown geometrical and material parameters. For a laminated composite, a tensile fracture, compressive buckling, or a combination of both types of failure modes is usually observed for flexural failure which implies that it is difficult to determine how energy is absorbed in a charpy/izod test on a composite.

On the contrary drop weight tests are more relevant since they represent more closely the impact configuration that is typical of many practical applications for composites. However data generated using different impact test methods – izod, charpy and drop weight may not correlate with each other. In general, mathematical models are not available to analyse the impact response of composites, and most of the semi-empirical approaches provide only guide lines to generate and interpret test
data. Therefore selection of composite type and test methods should conform to the stress states, geometric and boundary constraints, and other relevant variable limits as noted for a particular application.

1.6 *Governing equations*

1.6.1 Velocity:

\[ V = \sqrt{2 \cdot g \cdot h} \quad \rightarrow \quad \text{Eq. (1.1)} \]

Where \( g = 9.8 \, \text{m/sec}^2 \) \( h = \) drop height, Meters

1.6.2 Energy:

\[ E = \frac{1}{2} M V^2 \quad \text{where} \quad E = \text{energy} \quad \rightarrow \quad \text{Eq. (1.2)} \]

\( M = \text{mass} \quad V = \text{velocity} \) (The velocity change during the impact)

or

\[ W = F \cdot d \]

where \( W = \text{work} \quad F = \text{force} = \text{mass} \cdot \text{acceleration} \)

\( d = \text{distance over which the force acts} \).

The units for both \( E \) and \( W \) are Kgm\(^2\)/s\(^2\) or Newton-meters and so are equivalent.

In the case of drop weight tower:

\[ \text{Energy} = m \cdot g \cdot h \quad \rightarrow \quad \text{Eq. (1.3)} \]

where \( m = \text{weight (kg)} \quad g = 9.8 \, \text{m/sec}^2 \quad h = \text{drop height (m)} \)
Summary

In summarising at this point it can best be said that impact behaviour is a complex phenomena governed by the myriad constituents involving both the material aspects and the phenomenological aspects governing impact dynamics. There is a clear demarcation between low velocity and high velocity impacts both of which are governed by entirely different processes and effects. But the fundamentals of impact dynamics some of which has been discussed in this chapter is a commonplace in both.

References


