A REVIEW ON SHEET METAL FORMING AND ITS LATEST DEVELOPMENT OF SANDWICH MATERIALS

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ABSTRACT:
In recent years, there had been continuous research and development in the sheet metal forming processes, in order to satisfy the modern applications. Forming and its characterization play a vital role due to the limiting characteristics of metals being formed and the forming process parameters. The sandwich materials created rapid revolutions in the field of sheet metal manufacturing process due to their unique characteristics, such as high strength to weight. However due to their composite nature, during forming process many problems may arise. Hence the rate of material flow, the die cavity must be controlled so that better quality can be achieved in order to prevent defects like wrinkling, lining, tracing and tearing. This paper, basically aims to discuss the different types of metal forming processes, Forming Limit Diagram (FLD), fabrication of sandwich material to achieve excellent properties, applications, their merits and demerits corresponding to sandwich materials. The Forming characteristics and parameters which influences the sheet metal forming were discussed, viz. density, Poisson’s ratio, yield strength, ultimate tensile strength, total elongation, strain hardening coefficient, plastic strain ratio etc., Deep drawing process is discussed in depth in this paper for designing sandwich metal forming die and punch. In addition to the design and experimental setup for determining the forming characteristics of sandwich material the conceptual design is also discussed.

1. INTRODUCTION
The current modern advancement has requested a superior comprehension of sheet metal formability i.e., the capacity to be framed into carved shape and size keeping in mind the order to meet ones necessities [1]. Although numerous materials can be shaped, this paper is confined to the framing of sheet metals and their most recent advancements viz. sandwich materials [2-3]. Sheet metal shaping being one of the most seasoned systems has been honed by old Greeks and has been creatively connected through the ages by the blacksmith [4].

In the recent era, sandwich sheets and metal–plastic laminates have been developed in order to reduce the weight of vehicles and improve the sound-damping properties of materials [5-7]. The automotive industry has always paved path for new developments in sheet metal forming. For instance, the power-law strain hardening connection was just in view of the way that gentle steel complies with this connection great [8]. This connection, together with the strain hardening coefficient, is by and large utilized notwithstanding the way that numerous other material structures don't take after this connection [9]. The accentuation on expanded fuel effectiveness in vehicles and the push to lessen ozone harming substance outflows is driving examination into cutting edge lightweight materials. Certain investigation by Institute for Energy and Environmental Research (IEER) found that a lessening of 100 kg mass of traveler vehicles would bring about fuel funds in the vicinity of 300 and 800 liters over the lifetime of light vehicles and to more than 2500 liters for mass transport vehicles, for example, taxis and buses10. Lessening the mass of traveler vehicles by 100 kg likewise decreases the CO2 identical ozone harming substance outflows by around 9 gram for every kilometer.

The constantly progressing interest for new body shapes has prompted an constant increment in the interest for understanding sheet metal formability [1,3]. Stamp shaping is broadly utilized as a part of car and buyer merchandise businesses because of the capacity to mass create metal segments. Presently a day composite are made utilized widely in car applications, it is important to have the capacity to utilize a current innovation and further comprehend the learning to make parts out of these materials11. Give us a chance to consider a case of the aluminum sandwich sheet metal which is the material that is created by following two aluminum skins to one polypropylene or some other light texture or plastic or glass center. At the point when this has an indistinguishable twisting firmness from a steel sheet, it is 65% lighter than the steel and 30% lighter than aluminum alloy9. Along these lines, it is advised only as great substitutive materials for a steel body to enhance the fuel proficiency. Through aluminum sandwich sheet, however has generally bring down formability than that of the steel sheet for car application. Lightweight, high formability, damping resistance and low value sheet materials have been created with an appearance of electric vehicle as of late [12-13].

1.1. Definition of Formability
A material shows great formability on the off chance that it goes through the forming operations without displaying any issues [14]. Besides desired properties like great sound, high flexural stiffness and vibration damping, formability of the composites are basically one
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of major concern that should be improved before any attempt is made to substitute solid metal sheets with metal-plastic sandwich materials [14-15].

This definition however has a few inadequacies. The accomplishment of a shaping procedure relies on upon three variables like-the material being framed (work piece), the framing tooling and the procedure conditions like oil, clear holder settings and so on. A deficiency in the framing procedure, for instance prompting disappointment or break may have a cause in both of three, and frequently can be fathomed by changing any of these variables [16]. This shows the down to earth meaning of formability is quite recently halfway identified with the material. Subsequently a typical logical meaning of formability is: The formability of a material is the level to which that material can be twisted (extended) before crack happens [3]

1.2. Basic Formability parameter

Formability tests when being conducted at room temperature give rise to evaluation of various formability parameters [13] such as:

- Plastic strain ratio \( r \)
  It is the ratio of between width strains to thickness strain.

- Strain hardening exponent \( n \)
  It is a phenomenon exhibited by most metals and alloys in the soft condition where by the strength or hardness of the material increases with plastic deformation.

- Poisson Ratio \( 1/m \)
  Within the elastic limit, the ratio lateral dimension/longitudinal strain is represented by \( 1/m \) is a constant for a particular material and is known as Poisson’s ratio.

- Density \( \rho \)
  It defined in a qualitative manner, as the measure of the relative "heaviness" of objects with a constant volume. Its unit is Kg/m\(^3\).

- Yield strength \( \sigma_y \)
  The maximum stress that can be applied without exceeding a specified value of permanent strain is called yield strain. Its unit is N/m\(^2\).

- Ultimate tensile stress \( \sigma_u \)
  The ratio of maximum load to initial cross-sectional area of the sample is called the Ultimate Tensile Stress (UTS). Its unit is N/m\(^2\).

- Total Elongation \( E_{Tot} \)
  It is the aggregate sum of perpetual expansion in the way of the crack in the elastic test to disappointment; normally communicated as a rate of the first gage length. Its unit is m or mm.

1.3. The Forming Limit Curve

In a distorting sheet, the strain state is characterized as the proportion between minor strain and significant strain. The exploration in this field was spearheaded by Keeler, in view of the perceptions of research works that as opposed to utilizing a basic worldwide list, the neighborhood distortions must be considered [17-18]. The formability relies on upon the strain state and further can be communicated as the alleged shaping breaking point bends (FLC). In complex strain expresses the distortion is restricted by precariousness similarly as in a tractable test. In instances of negative minor strain this can be broke down essentially, in instances of positive real strain more mind boggling examination is required to be performed. There are two strain expresses that permit high formability: profound draw and equi-biaxial.
The FLC however is just legitimate under specific conditions: no twisting, straight strain way, planar anxiety, no shear [1,4]. This is shown is Fig 1.

![FLC constructed by Goodwin and Keeler](image)

**Figure 1** FLC constructed by Goodwin and Keeler [19]

The upside of Forming Limit Curves (FLCs) is that it can be effectively used to look at the formability of two unique materials. When, all is said done for numerical examination of framing conduct as far as possible charts [20]. FLDS can be acquired either tentatively or numerically [21]. FLCs additionally permit the advancement of limited component reenactment and the shaping of a material keeping in mind the end goal to decide the nearness to disappointment of a planned part [22].

1.3.1. Strain State and Conventions

As said some time recently, the formability is identified with the strain state. The strain state is the mix of the three main strains e1, e2 and e3. As its aggregate is thought to be zero, two are sufficient to indicate the strain state and it is basic to utilize e1 and e2 for that. The proportion between these two is ordinarily communicated as $\beta$: $e_2 = \beta e_1$ [1,3].

2. AN OVERVIEW OF EMERGING MATERIALS - SANDWICH MATERIALS

A composite which consists of alternative bonded thin metal sheets and fiber reinforced layers have been developed at Delft University of Technology, Netherlands [23]. There is a constant pressure on the automotive industry to come up with lightweight structural solutions to improve the vehicle’s fuel efficiency without compromising the structural performance [24]. In addition, the design choices are subject to stringent cost constraints as innovations in automotive engineering are seldom successful unless both performance and cost advantages prevail. Sandwich materials provide an excellent specific weight, stiffness and strength properties, but their uses are mostly limited due to low volume production and high production costs [24]. However, the stiffness of advanced high strength steels is the same as that of conventional steels. Hence, these materials do not provide better lightweight solutions.

Sandwich structures are known for their exceptionally-high flexural stiffness-to weight ratio. These Materials have grown steadily, conquering new markets relentlessly. Sandwich structures are usually made of two phases. One is reinforcement phase and other is matrix phase [25]. The hidden outline idea is the division of two level sheets by a considerably thicker center layer of low thickness as appeared in Fig 2.
Sheet metal and fiber reinforced plastics are normally picked as face sheet materials, it is a direct result of the decision of that low thickness center layer heat metal and fiber strengthened plastics are regularly picked as face sheet materials, it is a direct result of the decision of that low thickness center layer materials is more perplexing [27]. As for essential flexible and weight properties of the center layer, multi-usefulness and manufacturing considerations becomes an integral factor [4,28].

2.1. Forming of sandwich panels
Sandwich structures with particular bended mid-planes are difficult to make. As a result, it makes sandwich developments for the most part restricted to level board sort of structures decreasing their extent of uses. In different fields like aviation and automotive industries for instance, complex three-dimensional shapes are made by changing over level spaces by means of different sheet metal framing operations [29]. Subsequently, the improvement of another formable sandwich sheet material that could be utilized with traditional sheet metal forming technology is of great interest [30]. There are two main approaches for forming sandwich structures into three-dimensional shapes: building the different component parts into the required shape and assemble them to create the sandwich, or forming the sandwich structure directly [31-32]. This is shown in Fig 3.

Figure 2 Schematic illustration of Sandwich structures layup [26]

Figure 3 Simple representation of laminated sandwich panel [33]
3. METAL FORMING OPERATIONS FOR SANDWICH MATERIALS

Now a day though there are various methods being employed for the forming operations of composites, viz, sandwich materials. Some of the most common as well as important methods used specifically for the metal forming operation of the sandwich materials are Bending, Shear, Incremental forming, Ultrasonic forming [1,13].

3.1. Bending

About all shaping operations include some measure of twisting. In a circumstance of twisting joined with strain and pressure, the event of strengthening filaments at the sunken side makes extra security, subsequently raising the formability [34]. This additionally brings down the pressure drive [6,35]. A typical worry at the cutting instrument's contact has comparable impact, despite littler extent. Twisting can likewise make shear, or cause between crystalline crack in a portion of the materials at the arched side that clearly brings down the formability [36].

![Figure 4 The handkerchief-bending-test.](image)

The sheet’s piece is bent twice (A-B-C); no cracking is allowed in the corner of the double bend. Right a picture of an actual test carried out on 6 mm thick and high-strength steel [1]

3.2. Shear

There are three sorts of shear: in plane shear, thickness shear, and a straightforward out of plane shear. Shaping by unadulterated shear can on a basic level make interminable formability as there is no lessening in sheet thickness [37]. The circumstance of shear consolidated with extend is more intricate, yet a few investigations have demonstrated the way that it can raise the formability fundamentally after some time [1,13,38].

![Figure 5 S-shaped part showing the difference between stretch and shear](image)
3.3. Incremental Forming
In incremental shaping operations large amounts of disfigurement are effortlessly gotten. In Incremental Sheet Forming (ISF) elevated amounts of twisting are acquired by a blend of impacts specified above: bowing and shear [39-40].

3.4. Ultrasonic Forming
The use of vibrating instruments can improve the formability fundamentally. A major cause is the abatement of grating between the work piece and the device, additionally the formability in the strict sense can be expanded [41].

The utilization of a vibrating apparatus has been connected on a few sorts of framing operations, and the advantages of vibrating instruments have been especially exhibited with the end goal of profound drawing, divider pressing and wire drawing. Most such research has been completed on ultrasonic profound drawing. For this situation, either the clear holder ring, or the punch head, or both are vibrating. As the vibrating apparatus parts can make a considerable amount of clamor, most applications utilize ultrasonic frequencies of more than 10 kHz (thus the name), albeit low recurrence (1–50 Hz) or basically ultra-high recurrence (1 MHz) have been connected and in addition the constrained vibration of hardware part requires a decent lot of vitality. Thusly numerous applications utilize devices that are intended to have a specific resounding mode in the required recurrence extend, prominently in the event of radially vibrating rings [42-43].

3.5. Testing of Formability for sandwich structures
The point of formability testing is to judge if a specific material will pass a specific shaping operation or not [16]. This requires an intensive comprehension of the connection between press execution of a material everywhere, and its essential properties [37].

There are three sorts of formability testing: coordinate testing, simulative testing, and roundabout testing. All are pertinent for the characterization of sandwich material formability [3, 35].

3.5.1. Direct testing
It implies making the full-estimate part, either in press shop or research center. This kind of testing extraordinarily exhibits most direct connection between material parameters and press execution. These require much material (expansive spaces), extensive ventures (press and tooling) and, if the tests are completed in the press-shop, loss of generation time. Most
imperative of all it is costly and is when all is said in done exceptionally hard to make an interpretation of the discoveries to different parts [44-46].

3.5.2. Simulative testing
It implies completing the fundamental framing operation, yet on a littler item regularly of basic sort. This kind of testing permits the investigation of the impact of a few parameters generally snappy and shoddy. In profound drawing this could be the drawing of a little round and hollow item (the notable Swift-glass) This is utilized as a part of general to study impacts of material parameters like anisotropy, thickness, frictional impacts, additionally device parameters like kick the bucket span, punch sweep, unpleasantness, and process settings like clear holder compel, oil and so on. Many tests that have been created in the past have turned out to be out of date, for instance it is emphatically corresponded to parameters that can be measured with roundabout testing; a great case of such is the Yoshida clasping test. That does not imply that these tests have been an exercise in futility, despite what might be expected: they have helped us to pick up a superior comprehension of the connection between material parameters and press-conduct. As new and distinctive procedures do begin occasionally (like incremental shaping), new simulative tests are required too [45].

3.5.3. Indirect testing
It implies deciding some parameter that is known to affect the press conduct in a test that entirely is not a shaping operation. These tests are for the most part basic and fundamentally require minimal material. Be that as it may, the making an interpretation of results into the press conduct of the material while framing a mind boggling part is a long way from simple and requires an exhaustive comprehension of the shaping procedure. For basic parts it is less difficult: unadulterated profound drawing depends predominantly on strain solidifying relation(r), while immaculate extending depends principally on strain solidifying co-productive (n) [13].

Figure 7 Depicts all the parameters that influence the formability of a sandwich structure

3.6. Flow Parameters influencing formability of sandwich materials
There are various parameters that influence the forming nature of a sandwich structure. Certain primary components are property of the material, process parametric influence and other miscellaneous parameters. One must always consider these parameters in mind before designing or manufacturing any complex sandwich structure [47]. Its flowchart is as follows.

http://www.iaeme.com/IJMET/index.asp 376 editor@iaeme.com
3.7. Formability criteria for sandwich materials

Diminishment of fuel utilization with synchronous change of solace, aloof and dynamic security and comparable, speaks to an imperative objective of all auto makers. With that aim, amid the most recent couple of years, materials for fabricate of diminished weight auto bodies were progressively more utilized; such materials are: high quality steel and Al-sheet metals, titanium and its compounds, sandwich and composite materials and comparative. Contemplating the long haul use of for all intents and purposes no different materials with the exception of low carbon steel sheets for that reason, move to use of rather new materials prompts numerous innovative challenges.

![Limiting Formability Criteria](image)

**Figure 8** Relates the criteria for the formability of sandwich structure

When outlining the innovation for the procedure of metal framing by profound drawing, it is critical to know constraining formability, which can be characterized as capacity for acknowledging maximal strains in given shaping conditions (stretch strain plot, speed, temperature, tribiological conditions and so forth.). In that way, restricting formability is one of delimiting components when characterizing formability that additionally incorporates complex criteria for appearance of insecurity (wrinkles, limitation –thinning, diversion), break and so on.

4. DEEP DRAWING PROCESS

4.1. Deep Drawing of sheet metals

Deep drawing is one of the most important sheet forming processes which is used in the automotive, home appliance and aerospace fields. The limits of this process are the onset of wrinkling, fracture and failure. Though it has to meet great demands in market for safer, lighter and cheaper formed products, it is necessary to select the proper drawing parameters which influence the drawing operation [48]. The advance researches on the deep drawing process and its effective parameters include the following: Mohr and Straza (2005) showed that unlike conventional flat sandwich panels, sandwich sheets, with a thickness of about 2 mm or even less, can be formed into three-dimensional shapes using traditional sheet metal forming techniques such as stamping or draw bending. Mohr (2005) studied the formability of two different sandwich plates with stainless steel face sheets, with stainless steel fibres and steel perforated cores [49].

Deep drawing experiments and a detailed numerical and theoretical analysis of the bending and unbending behaviour of the sandwich sheet revealed that cellular core structures
of high relative density (>20\%) are required to withstand the high shear loads during forming [50-51]. With these results in mind, Seong (2010) designed map to create a bendable all metal sandwich structure with a better core. It shows that the shear strength of core is increased as the gap between bonding points between the core and the face sheet decreases. An investigation was performed on the suitable experimental set-up and geometric conditions for avoiding delamination failure during U-bending experiments on a welded sandwich plate. Considerations on the core geometry to avoid face sheet buckling were thought of to design an optimal sandwich sheet and carry on bending experiment [52].

In contrast to conventional structures like egg-box, the contact areas variation between the core structure and the sandwich face sheets are ring shaped which reduces the risk of face sheet wrinkling or dimpling when the sandwich material is subject to bending [53]. Fig 9 shows an illustration of the successful draw bending of a prototype made from this material.

![Technical drawing of the experimental set-ups](http://www.iaeme.com/IJMET/index.asp)

**Figure 9** Technical drawing of the experimental set-ups:

(a) four-point bending experiment, (b) draw bending experiment [54]

To have a detailed review the different interaction of the parameters in deep drawing for producing a required shape say for example a cup the following notations have been used.

- **Do**: Diameter of a circular sheet blank.
- **to**: Thickness of the circular sheet blank.
- **Rd**: Corner radius of the die opening.
- **Dp**: Punch diameter.
- **Rp**: Corner Radius of the punch.
- **WP**: Plastic Work required for deep drawing.
- **Vo**: Initial volume of blank to be drawn.
- **Vc**: Volume of drawn cup.
- **ε**: The effective strain.
- **σ**: Effective stress.
Certain independent variables that govern punch force are:

- Properties of the sheet metal
- The ratio of blank dia to punch dia $R$
- Sheet thickness
- The clearance present between die and punch.
- Punch and die corner radii.
- Blank holder force.
- Speed of punch.

5. PROS & CONS

5.1. Pros of using metallic formed sandwich materials

- Making flying machine, vehicle structures and parts. At first the military applications in the air ship industry set off the business utilization of composites after the Second World War. The advancements in the sandwich structures permitted noteworthy weight diminishment in auxiliary outline. Sandwich materials offer many focal points when contrasted with other metallic amalgams, particularly where high quality and firmness to measure proportion is concerned, they give phenomenal exhaustion properties and consumption resistance in applications.

- Better fire retardant property. With the help of various experimental analyses, we can easily conclude as a sandwich material has a better fire retardant property compared to any other basic metal.

- Possesses good mechanical properties. Sandwich materials can resist a larger amount of strain and displacement compared to other metallic alloys, these can be finalized by the analysis of the material structure. This intern provides a better mechanical property to the sandwich materials.

- Good corrosion resistant. This is an important characteristic of a sandwich material i.e., their resistant ability to form ions in the presence of reactive electrolyte. This improved nature provides a broader scope in the usage of sandwich materials.

- They are highly sustainable and typically have low maintenance. Sandwich structures can be widely used in sandwich panels this kinds of panels can be in different types such as FRP sandwich panel, aluminum composite panels etc. With an enhancement in
their properties, the maintenance of sandwich materials gradually dips down. This is also an improved physical phenomenon due to which the sandwich materials sustainability is better compared to other alloys [57].

![Figure 11](image1.png)

**Figure 11** Representative graph that shows relation between modulus and strength of various sandwich structures

The above plotted graph simply depicts the relationship between the specific strength and modulus over the usage of various sandwich materials in comparison with the old and conventional ones that are already used in various automotive and aviation industries, where there is a greater requirement of new composites which provide better performance with respect to low weight and a high stiffness & strength ratio. This could help them greatly in improving the design, fuel efficiency, safety etc. [50-60].

### 5.2. Cons of using metallic formed Sandwich Materials

- Sandwich structures uses is more challenging and are less predictable.
- Sandwich structure health monitoring and nondestructive inspection of former is much more difficult than for metals [37].
- They tend to absorb moisture.
- One of the most common types of layered composite failure is delamination, i.e. debonding of one layer from another [49,61].
- They are expensive.

### 5.3. Applications of sandwich structures

Because of the incomprehensible beneficial properties of sandwich structures, they can be utilized in various fields for better execution and proficiency. They assume a fundamental part in enhancing the wellbeing measures where it is most extreme required. Sandwich materials are chiefly utilized as a part of aviation and vehicle applications [62-63, 69]. Different organizations have enthusiasm for substitute the conventional aluminum segments by sandwich materials [64]. Fiber Metal Laminates being a type of sandwich materials have been effectively brought into the Airbus A380 [62,65,66], other fiber metal overlays like both ARALL and GLARE covers are presently being utilized as basic materials in airplanes. ARALL has been produced for the lower wing skin boards of the more established Fokker 27 airplane and entryways of the Boeing C-17 [23, 48].
6. CONCLUSION

In this work, the basic overview of the metal forming process in relation to the preparation of sandwich materials is studied. Also certain important method of sandwich materials formability, its criteria and parameters were reviewed in an elaborate manner. The pros and cons of using sandwich materials at various day to day as well as a broader scale application was discussed.

- The solution of using sandwich materials as an alternative for automotive and aerospace applications was deemed beneficial in all aspects. With an improved manufacturing process like metal forming, the sandwich materials could be put for a better use.
- Though implemented in certain areas its awareness is comparatively lower, due to its small drawbacks like cost, debonding, monitoring etc.
- Sandwich materials provide a better safety and an improved efficiency compared to any metals that are being used traditionally under various applications.
- In future studies, various numerical and structural analyses can be done in order to obtain an elaborate result over the actual conceptual model that has been developed using this work.

Development for future

The present work is a first step towards the modeling of the better metallic sandwich sheet materials with improved techniques for forming it. However, in order to ensure the validity of the developed conceptual or theoretical model about the techniques for manufacturing the sandwich materials, additional experimental and numerical studies are needed. It is recommended to characterize the limits of the applicability of the proposed constitutive model in future work. For instance, the utilization of the sandwich materials in aerospace requires a lot of analysis and calculation as, it is a very precise unit that demands higher safety and efficiency. A more elaborate flow rule and the introduction of additional state variables would allow for a more precise description of the microstructure evolution.

The confrontation of the model predictions using different forming techniques with experimental results on real prototype sheets is also an important task that needs to be addressed in the future. Apart from validating the plasticity model further, future research needs to investigate the forming limits of metallic sandwich sheet materials. Once the prototype material becomes available in the form of large sheets, various tests like [67-68] could be performed. It will be of particular interest to identify sandwich sheet specific damage mechanisms (such as face sheet dimpling and de-lamination) and formulate the corresponding forming limit diagrams, in order to have a better and safer conclusion about using such materials in a wider scale of application Camille Bessel [57].

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