A REVIEW: INVESIGATION OF PARAMETERS OF CORRUGATED WIRE MESH LAMINATES

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ABSTRACT

It has been observed that corrugated laminates have highly anisotropic stiffness properties and hence, it has many engineering application. Geometrically, CWML has critical applications with large deformation because of its non-linear stiffness response. Current paper discusses the mechanical behaviour of CWML and suggests a model to analyze corrugated structures. The mechanical response mainly depends upon the parameters such as geometry of corrugation, corrugation angle, number of corrugated layers, structures of laminates of the CWML and the material properties. In Testing, at first the samples of aluminium wire mesh laminates for different geometrical parameters are prepared and then tested for compressive and strength by using universal testing machine. Results obtained by experimentation are validated by using design of experiments and ANOVA.

KEYWORDS: CWML, Compressive strength, corrugation angle, ANOVA.

1. INTRODUCTION

It has long been seen that for forming light weight structures with high anisotropic performance, stability under buckling load and energy absorption capability, "Corrugation" is described as a series of parallel ridges and furrows. In engineering, structures having corrugation on its surface are called as corrugated structures. By adding different face sheet of different or same material on lower and upper surfaces, for getting new structure, is called corrugated panel or corrugated laminate. CWML has various industrial applications and numerous innovative developments to corrugated structures, involving more elaborate and ingenious corrugation geometries and combination of corrugations with advanced materials. [1]

By combining several layers of metallic wire meshes on top of each other, CWML is manufactured. Corrugations can be made by using manufacturing methods like bending, folding, punching or moulding. Due to their open structure and the mechanical properties of the parent material, CWML can offer high stiffness and strength per unit weight. Therefore, they have many potential applications where lightweight and high rigidity and strength are required, such as core material in sandwich constructions in mechanical and aerospace engineering, and orthopedic implants in biomedical engineering. Corrugated structures also have applications in packaging industry, civil structures, marine structures and mechanical engineering structures. The main loading in such applications is transverse compression, occasionally accompanied by in-plane shear. The strength of CWML depends on the several geometrical parameters involved in the configuration of structure [3]. The objective of this paper is to find out the effect of geometrical parameters like corrugation profile, corrugation angle, laminates structure and number of corrugated layers on the strength of CWML. For this purpose, samples of CWML will be produced in the combinations of three different levels of corrugation profile, corrugation angle, laminates structure and number of corrugated layers. The strength of each structure will be recorded by subjecting them to compression test or tensile test. By applying design of experimentation technique, using Taguchi methodology results will be analyzed and optimum levels of each controlling parameter will be determined for maximum strength of CWML [2]. By using ANOVA methodology the optimum results are found and verified.

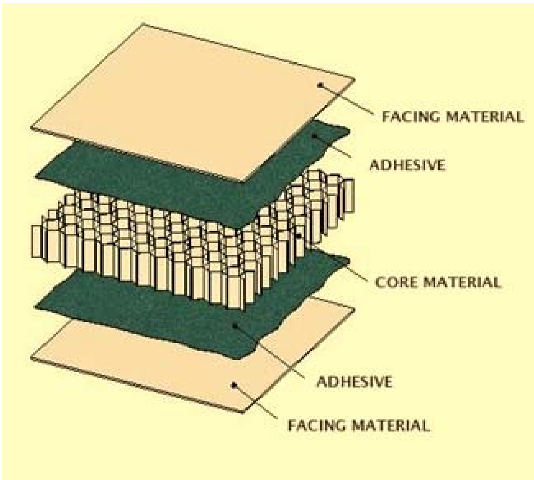

FIG.1.1 Laminate

1.1 MECHANICAL PROPERTIES OF CWML

Experimental and finite element analyses develop a set of analyses about flexural, tensile, shear and out of plane compressive strength of corrugated panels. These analyses have considered mainly the nonlinear effect of material properties and geometric parameters as well as analysis of various boundary conditions and loading configurations [3]. When possible in the literature, analytical solutions are introduced in support of these investigations [1].

1.1.1 Bending:

Numerous studies have been conducted on the bending stiffness of corrugated board. These investigations have integrated analytical solutions, finite element simulations or experiments to find the flexural rigidities of the board. By using three-point bending test, the effects of the Corrugation curvature, web thickness, material properties of the corrugated web and the corrugation direction on the beam’s load-carrying capability are determined. The experimental tests were conducted to validate the results obtained by nonlinear finite element analysis. The 30% difference in the flexural stiffness which was observed in the results highlighted the bending anisotropic characteristics of the composite beam with the corrugated web. It was also reported that increasing the radius of corrugation curvature led to higher bending stiffness and could reduce the beam’s weight by about 14%. [1]

Dayyani et al. [1] studied the flexural characteristics of a composite corrugated sheet using mathematical and analytical methods and validated the results by comparing them to the experimental data. A good degree of correlation was observed in their work which evidenced the suitability of the analytical method and finite element model to predict the mechanical behaviour of the corrugated sheet in the linear and nonlinear phases of deformation.

1.1.2 Tensile:

Noting the extreme anisotropic stiffness properties of corrugated sheets, Thill et al. [3] investigated the effect of a variety of materials and parameters such as number of plies and corrugation pitch on the overall mechanical properties of the corrugated composite sheet. The output of this study was that the transverse tensile elastic modulus is dependent on the squared laminate thickness and the length of corrugated unit cell length. Three years later, they explained the obtained results via experimental, analytical and numerical analysis methods. They considered trapezoidal corrugated aramid/epoxy laminates subjected to large tensile deformations transverse to the corrugation direction and highlighted the effect of local failure mechanisms of these specimens on the three stages of the tensile force–displacement graphs. They found out that the second stage, which comprised the majority of the displacement, occurred because of aramid fibre compressive properties and de-laminations in the corner regions of the corrugated unit cell. This local phenomenon was compared to a pseudo-plastic hinge allowing large deformations over relatively constant stress levels. In these three stages, the tensile force–displacements are plotted. The plasticity was exploited in finite element simulation as a technique to model the de-lamination, which dissipated the strain energy of the system during the tensile testing. Assigning the plasticity to all of the regions of the corrugated unit cell resulted in a good agreement between the numerical predictions and the experimental observations. The extreme sensitivity of the composite corrugated sheet to the angle of the corrugated unit cell was also demonstrated in this work which highlighted the importance of the precision of the design and manufacturing process.

1.1.3 Shear and compression:

Transverse shear stiffness of the corrugated sandwich panels is one of the important characteristics of these structures which must be accurately characterised in the performance analysis of these structures. Among the early works regarding this issue, curved beam theory to study the shear stiffness of a corrugated cardboard is used. Researcher presented a theoretical study on how the geometry of the corrugation affects the transverse shear moduli. In that study by assuming rigid face sheets in the corrugated cardboard they derived an upper limit of the transverse shear modulus across the corrugations and then showed how this shear stiffness reduces if deformations of the face sheets are considered in the analysis. Nordstrand and Carlsson [1] experimentally examined the effective transverse shear moduli in the principal material directions of corrugated board using the block shear test and the three-point bend test. They observed that the shear moduli obtained by the three-point bend test were almost half of those determined by the block shear test. This discrepancy was explained by local deformation of the face sheets of the board where they were in contact with the supports in three point bending test.

Isaksson et al. [4] considered a panel of corrugated paper board as a stack of an arbitrary number of thin virtual layers with corresponding effective elastic moduli. The elastic properties of all layers were assembled together to analyse a corrugated board as a continuous homogenous structure. They showed that exploiting the shear correction factors which were derived from the equilibrium stress field can improve the stiffness calculations. Their proposed model was validated by experiments on corrugated board panels with different geometries.

Likewise, the effect of hierarchy on the stiffness of corrugated structures in compression has been followed by other researcher [1]. They have applied sandwich panel with PMI foam to the local inclined members of the global corrugated core and experimentally studied a range of different failure modes of these structures depending on their geometrical and the material properties. In this regard, first the collapse mechanism maps of different corrugation configurations were analytically obtained. The stiffness model exploited the contribution in stiffness from the bending and the shear deformations of the local core members in addition to the stretching deformation. They claimed that the proposed hierarchical corrugated core can have more than 7 times higher weight specific strength, compared to its monolithic counterpart, if designed correctly. The difference in strength arose mainly due to the increase in buckling resistance of the sandwich core members compared to the monolithic corrugated core. It was observed that when the density of the core increases, the monolithic core members get thicker and more resistant to buckling and thus the benefits of the hierarchical structure reduces.

1.2 SECONDARY PROPERTIES OF CWML

1.2.1 Buckling:

Buckling occurs when a structure makes a rapid change of configuration due to applied load – this applied load may be compression, shear or multi-axial. A structure is often said to have failed when buckling occurs (for example when a column collapses under axial compression), and in these cases all that must be understood is when the onset of buckling will occur, which is usually a linear problem that can generally be achieved through classical analytical methods or using finite element analysis. However, in certain cases (such as in-plane shear buckling of a panel) some load resistance remains after buckling, and this so called post-buckle strength may be exploited. The study of post-buckling is often more complex than that of buckling, and the complex deformations formed during buckling often require the use of nonlinear analysis.

One of the most common methods to analyse buckling of corrugated plate or shell structures is to use a model to homogenise the corrugation as an orthotropic panel, and then to find global buckling modes using analysis similar to conventional panels. Many examples of this approach are presented subsequently. Although a variety of homogenisation methods exist an

FEA unit cell may be used to derive the equivalent properties if an analytical process is not available.

Moreover it is usually possible to make further checks on corrugated structures especially for the configurations which have flat sections, such as trapezoidal corrugations, to ensure that local buckling modes do not occur. However, this approach cannot be applied in a straightforward manner to continuous profiles e.g. sinusoidal corrugations. If it is not feasible to simply check local and global modes separately, or greater accuracy is required, higher fidelity analyses must be used. Clearly, Finite Element methods have a broad role to play, however other higher fidelity methods exist. The mesh free Galerkin method is used to analyse the buckling modes of a plate. This method was an alternative to FEA analysis, with the advantage that it could avoid certain problems with element distortion. Finite strip method, with nonlinear kinematics is used to study in detail the situations where the global mode interacts with local modes to create a localised region of buckling in the post buckled shape, and reduce the critical load. The work also considered how these interactions led to sensitivity to initial imperfections. Few authors use fully analytical methods to consider both global and local features of a corrugated structure simultaneously [1].

The literature on buckling of corrugations is separated into the following applications: webs of beam sections, shell structures, naval structures, and the packaging industry.

1.2.3 Vibration:

Vibration is an important consideration throughout engineering; the demand for low weight can often result in structures with low damping present, which can result in destructively high amplitude vibrations, if modes are excited at their natural frequencies. In general, structural vibration is also an issue of importance for topics such as noise and passenger comfort in vehicles. It is also an important subset of the wider field aero elasticity, which may be a particularly crucial problem for morphing aircraft where structures are specifically designed to include compliance for actuation reasons. Relatively little work has been dedicated specifically to the vibration of corrugated panels, although clearly many general methods such as FEA are applicable.

Many studies rely on homogenised models of the corrugation to analyse vibration; these have the advantage of simplicity, but have the disadvantage that they may not account for ‘local’ effects within the structure of the corrugation or behaviour that lie outside the assumptions of the fitted model. However, in many cases these deficiencies may simply be addressed with a further check.

Linear analysis of a simply supported sandwich plate with a corrugated core; many of the modelling assumptions were directly applicable to corrugations with covering skins. The model considered first order shear effects, however shear deformation was assumed to be negligible along the longitudinal direction of the corrugation. This assumption led to an elegant derivation with closed form solutions that may be readily used in optimisation.

Mesh free method is used to understand the vibration of a stiffened corrugated plate. The approach used a homogenisation technique that accounted for first-order shear effects in the panel; the mesh free method was a numerical method but had some advantages to FEA when applied to optimisation problems, because there was no requirement to regenerate meshes after geometry changes. [1]

Other works consider the effect of corrugation on the vibration of shells like deep shell theory and the Hamilton principal to provide a comprehensive study of the vibrations of a corrugated cylindrical shell, in manner that captures both local and global effects simultaneously. It was shown that homogenized approaches capture the first vibration mode only over a limited range of the corrugation pitch; if the pitch is too long, local modes will occur as the first mode, and if the pitch is too fine then in-plane vibrations occur. In another analytical survey based on deep shell theory, the geometric conditions that could lead to the presence of Rayleigh waves along the free edge of a corrugated cylindrical shell.

An energy harvester, using a corrugated plate as the vibrating element; where the purpose of the corrugation was to allow deformations that alter the natural frequency to match the most prominent ambient vibration frequency. This is an important phenomenon that will affect the vibration of corrugated skins; that their natural frequencies will be strongly influenced by their states of deformation like power density, which is largely determined by the natural frequency, was shown to vary significantly with the span length of the corrugated strip.

Experimental studies concerning the vibrations of corrugated plates seem to be somewhat rare. The first work concerns the vibration transmitted through plane vibration, and finds that the presence or size of corrugations has little conclusive effect. The latter considers the loss factors of different modes of flexural vibration of the plates, and shows that corrugations cause slightly higher loss factors for the first mode, with the effect increasing with increasing corrugation depth. The study of vibration considered the influence on modal properties of material thickness, corrugation depth, corrugation angle and also whether corrugations ran around the circumference or along the length of the cylinder. However, there are many different option of corrugation geometry that remain to be considered by these works; indeed no work can be considered as directly relevant to morphing corrugations because they both consider rigid corrugations only.

Not all work is dedicated to rectangular platforms; in the flexural stiffness and vibration of circular corrugated plates, with the primary motivation being components of precision machinery. Some studies show energy based approach to reformulate the response of the corrugations in a radial coordinate system, and also allows for large deflections. However, few practical morphing aircraft components will meet the symmetry requirements of the model developed.

1.2.4 Impact: There appears to be no literature that is directly concerned with impact loads on corrugated skins within the context of morphing aircraft. However, the low-velocity impact performance of corrugated panels and sandwich cores has been widely studied in other applications. In general, this interest is due to the complex deformations that can occur in a corrugation as it is impacted and potentially crushed; internal buckling, contact friction and plastic deformation can all occur, and these may be seen as energy absorbing processes, therefore may protect other elements in the structure from damage.

Variety of corrugated forms for use in an impact energy absorber, of these forms includes an interesting arrangement of two layers of corrugation in close proximity, so that frictional contact between the layers dissipates yet further impact energy. Impact on corrugations made from bamboo fibre based composites; finds that the laminate stacking sequence and corrugation direction have a complicated effect on the impact energy absorbed by the impact, with a unidirectional layup with fibres oriented along the corrugation channels being optimal.

However, the choice of different layups led to completely different failure modes in response to impact, with the mode varying between tensile fibre failure, de-lamination or local buckling. A different approach to the impact of corrugations in which corrugations impacted by waves of liquid, and the complex dynamics that arise due to trapped gas bubbles that become pressurised as a result of the wave impact.

More literature is dedicated to corrugations when used as cores in sandwich panels, and while a full review of sandwich panels under impact is beyond the scope of this section, a few examples are listed here, are sandwich panel with a phenolic foam core, reinforced by an FRP corrugation, with simulations of an impacting ball and impacts on a multi-layer stack of aluminium honeycomb sandwiches.

However none of these studies address structures that are designed to have the flexibility required for morphing aircraft or adaptive structural elements. In this context the idea of exploiting the complex deformation of corrugations under impact as means of energy absorption is feasible, only if the damage caused by impact is reversible (buckling with no permanent deformation), or limited to an extent that does not impinge on the structural and actuation requirements of the corrugation. However, if these requirements are met, it should be possible to develop corrugated skins with benign characteristics under impact. There remains much scope for new studies that consider the more flexible types of corrugations considered for morphing applications.

1.2.5 Fatigue: In the context of fatigue of corrugated plates, very little research has been carried out. The few works published in this area focus mainly on the investigation of girders with corrugated steel webs, whose main applications can be found in highway bridges. Here, the use of corrugated plates in girder webs represents an alternative to achieve considerable out-of-plane stiffness and buckling resistance without the need to use stiffeners or thicker web plates.

A typical configuration of a corrugated web consists of folds parallel and inclined to the longitudinal direction of the beam.

In this context, the fatigue assessment of welds joining corrugated steel webs to flange plates, the study revealed that most of the cracks initiated at the weld toe of the external weld line of the transition curvature and propagated through the main plate thickness.

The fatigue strength of the test joints was improved with the decrease of the corrugation angle, such an improvement was found to be less significant when corrugation angle increased over 45.

In the investigation of (analytical and experimental) the carbon fibre-reinforced polymer strengthened welded joints with corrugated plates. Fatigue crack generally occurred in the region of the transition curvature between the longitudinal fold and the inclined fold of the corrugated plate. The joints with transition curvature region reinforcement and single side reinforcement produce slightly lower rigidity but longer fatigue life in contrast to those with full width reinforcement on the double side of the main plate.

The fatigue strength of the web-flange weld by means of finite elements and crack propagation analysis studies concluded that the fatigue strength is affected negatively by the existence of the longitudinal folds of the corrugated web. It is necessary to have a large bend radius to eliminate the influence of the longitudinal folds.

Steel corrugated web I-girders exhibit a fatigue life longer than that of conventional steel I-girders with transverse stiffeners. The combined loading condition on the corrugated web girders has a significant influence on the fatigue life. The weld size is important from the point of view of fatigue design. By using a smaller weld size, the fatigue life of the girder is longer and therefore, use of the minimal required weld size for design purposes is preferred.

The fatigue life can be improved with the trapezoidal waveband without a significant decrease in the static capacity. Experimental results revealed that, holes with penetrating reinforcement were more effective than studs in the case of composite girders with corrugated web. [1]

2. MOTIVATION

1. Requirement of advance material having high strength and light weight for aeronautical industry
2. Requirement of advance material having definite stiffness value and flexibility in biomedical sector for bone replacement.

3. OBJECTIVES

1. To determine the effect of geometrical parameters like corrugation angle, laminate structure and number of corrugated layers on the strength of CWML.
2. To find out best analytical model for selection of optimum values.
3. To validate the results obtained from experimentation by using DOE's and ANOVA.

4. APPLICATIONS

Corrugated structures have wide application in engineering due to their special characteristics such as: anisotropic behaviour, high stiffness to weight ratio and high capacity of energy absorption.

The applications of these structures can be classified into the following categories in which more value is given to the special features of these structures.

4.1 Packaging industry: Corrugated boards, either made of plastic or cardboard are used extensively to produce rigid shipping containers of almost any shape or size. The packaging containers are exposed to various load conditions such as: static loads due to the compression of packages in a stack during transport and storage and vibration loads during transport. The reason that the corrugated sandwich panels have received huge interest in the packaging industries is because of their stiffness and durability, lightness and cost effectiveness as well as the recyclability and sustainability with the environment [7, 8].

4.2 Civil structures: The wide application of corrugated structures in civil engineering may be classified mainly as: beams with corrugated web, corrugated roofs and walls and corrugated pipes.

Beams with corrugated web: The main benefit of applying corrugated web beams in supporting roofs, floors and columns in steel structural buildings are that the corrugated webs increase the beam's stability against buckling.

Applying these corrugated web beams in the components of the building results in a very economical design by reducing the required web stiffeners and leads to a significant weight reduction in these beams compared with hot-rolled or welded ones [9].

Corrugated sheets in roof and walls: Corrugated sheets are among the best candidates for application in construction elements, for roofs, claddings and walls, of modern industrial buildings owing to their high strength to weight ratio, much lighter and lower cost than flat isotropic panels of the same strength [10]. Corrugated metal sheets for instance are frequently used as the roof of buildings that have steep slopes to dispose of rainwater quickly. Their combination of high stiffness and lightweight nature lightens the load on the installation and the underlying building structures.

Corrugated tunnel and pipe: Large metal corrugated pipes or arches are frequently used in tunnel structures to transport the aggregate and ore across various points on their properties. The need to maximise the surface area on such sites necessitates the use of tunnels for transporting bulk materials under roadways and processing these materials. The application of corrugated pipes and arcs in these tunnels offers advantages in the design, installation and operation of these projects such as: reducing the design time and related costs; simplicity of construction which leads into the reduction of installation and maintenance costs [10]. Corrugated pipes are often used in sewerage and drainage applications because of their light weight, high strength and compliance which lead into long life performance. The strength of the pipes arises from the corrugated design of the outer wall rather than the wall thickness, in contrast to the normal solid wall pipes. The advantages of the corrugated pipes in general can be classified as their lightness and flexibility. The lightness of these structures reduces the manpower needed for installation and the costs of transportation whereas the flexibility reduces the damages during storage and handling and ease the natural settlements to be tolerated without suffering cracks or leakages [12].

4.3 Marine structures: The corrugated sandwich panel has offered a wide range of attractive design solutions to operational shipboard problems in which structural performance and weight are important design issues. The applications of these structures include decks, bulkheads, heli- decks and accommodation modules [13]. Another application of the corrugated sandwich panels is in the combatant deckhouse structure of a naval ship since these structures show a good resistance to the possible blast loads [14].

4.4 Mechanical engineering structures:

Corrugated hoses: Corrugated hoses are another case of important engineering structures which are exploiting corrugation characteristics. Because of the special properties of the corrugation structure, these hoses can withstand very high pressure and provide maximum leak tightness. Corrugated hoses also exhibit corrosion resistance and pressure tightness under the most extreme conditions, such as aggressive seawater, extreme temperatures found in space and conveying very hot or cold substances. The other advantage of corrugated hoses is their flexibility which makes them a good candidate to connect elements where they are subjected to movement, thermal expansion and vibrations [15]. Due to these characteristics they are frequently used in hydraulic circuits, protection for electrical cables and light conductors or exhaust gas installations.

Corrugated gasket: Surface configuration of the corrugated gaskets enables them to adapt to rough or irregular flange surfaces without requiring excessive compressive load. This provides an efficient seal under varying conditions of temperature and pressure. The substrate corrugation geometry promotes the recovery and resilience through thermal cycles and extended service life. Hence they are excellent products for both standard flange and heat exchanger gaskets where low bolt load are present or where high gasket stresses are available [7].

4.5 Aerospace and aeronautics application concepts:

Corrugated sandwich panels are used in aerospace engineering because of their multifunctional characteristics. These structures offer insulation as well as load-bearing capabilities in addition to their lightness. These multifunctional integral thermal protection structures protect the spacecraft from extreme 73e-entry temperatures, and possess load-carrying capabilities [4, 5, 6]. Moreover, because of their exceedingly anisotropic behaviour of these structures they have been proposed as a flexible skin for the wings of morphing aircraft. This is due to the fact that wing structures must be stiff so as to withstand bending due to aerodynamic forces, and flexible so they can deform efficiently in flight due to morphing actuation [8].

Corrugated structures, innovation and developments: As discussed so far, corrugated structures have noticeable impacts on the engineering applications due to their superior structural characteristics which mainly arise from their geometric properties. However the structural performance of these structures is being developed further in the literature by introducing more geometric parameters or using different material properties.

5. LITERATURE SURVEY

Dayyani et al. [1] studied the flexural characteristics of a composite corrugated sheet using numerical and analytical methods and validated the results by comparing them to the experimental data. A good degree of correlation was observed in their work which evidenced the suitability of the analytical method and finite element model to predict the mechanical behaviour of the corrugated sheet in the linear and nonlinear phases of deformation. The finite element simulation exploited the node to surface and frictionless contact technique, to model the interaction between the corrugated sheet and the supports. The force–displacement curves showed three distinct phases of deformation in the three-point bending test. Three phases of the deformations were distinguished as: deformation due to pure bending of corrugated sheet, deformation due to combined bending and axial forces causing a step increase in the force–displacement curve and again deformation due to pure bending of the corrugated core. They reported that the second phase in which the step was observed arose because of simultaneous contact of the two adjacent corners of the corrugated unit cell with the support.

Jeongho Choi, et al. [5] performed three-point bending tests on the bi-directional corrugated sandwich panels for various core orientations and demonstrated that this sandwich corrugated panel has a quasi-isotopic bending behaviour. They explained the effect of geometric parameters of the bi-directional corrugated core on the buckling strength of the face sheets during large bending deformations.

Isaksson et al. [3] considered a panel of corrugated paper board as a stack of an arbitrary number of thin virtual layers with corresponding effective elastic moduli. The elastic properties of all layers were assembled together to analyse a corrugated board as a continuous homogenous structure. They showed that exploiting the shear correction factors which were derived from the equilibrium stress field can improve the stiffness calculations. Their proposed model was validated by experiments on corrugated board panels with different geometries.

Jeongho Choi, et al. [6] gives brief introduction about manufacturing methods of CWML. Two different methods of fabricating corrugated wire mesh laminates from stainless steel, one using a high temperature Lithobraze alloy and the other using a low temperature Eutectic solder for joining the corrugated wire meshes are described herein. Their implementation is demonstrated by manufacturing CWML samples of 304 and 316stainless steel (SST). It is seen that due to the facility of employing wire meshes of different densities and wire diameters, it is possible to create CWML laminates with a wide range of effective densities. The fabricated laminates are tested under uniaxial compression. The variation of the compressive yield strength with relative density of the CWML is compared to the theory developed by Gibson and Ashby for open cell structures. It is shown that the compressive strength of the corrugated wire mesh laminates can be described using the same equations by using an appropriate value for the linear coefficient in the Gibson-Ashby model.

Jeongho Choi, et al. [7] from it is seen that all metallic corrugate core sandwich panels as primary loading structures may rapidly soften under compressive loading due mainly to core member buckling once the peak compressive stress is reached, resulting in reduced load-carrying capability. Inserting close-celled aluminium foam into the corrugate core has been envisioned as a feasible way to enhance the load capacity. The enhancement due to foam filling were firstly explored experimentally under quasi-static out-of-plane compression and the underlying mechanisms subsequently numerically studied using finite element simulations. The foam filled corrugated panel was found to have strength and energy absorption much greater than the sum of those of an empty corrugated sandwich panel and the aluminium foam alone. It was demonstrated that the core members in the foam-filled panel were considerably stabilized by the filling foam against lateral deflection. In particular, the elastoplastic buckling wavelength of the core members was significantly reduced and the transition from axial deformation to bending of the core member was much delayed, both of which contributing to the enhanced strength and energy adsorption capability of the foam filled panel.

Jeongho Choi, et al. [6] show a possibility of corrugated wire mesh laminate (CWML) structure for bone application. CWML is a part of open-cell structures with low density and high strength built with bonded mesh layers. Specimens of CWML made of 316 stainless steel woven meshes with 0.22 mm wire diameter and 0.95 mm mesh aperture, bonded by transit liquid phase (TLP) at low temperatures, were fabricated and tested under quasi-static conditions to determine their compressive behaviour with varying numbers of layers of the sample. The finite element software was used to model the CWML and studied their response to mechanical loading. Then, the numerical model was confirmed by the tested sample. Consequently, CWML specimens were reasonably matched with the human tibia bone ranged over apparent density from 0.05 to 0.08 g/cm^3 in Young's modulus and from 0.05 to 0.11 g/cm^3 in compressive yield strength. It is seen that the CWML model can have the potential for bone application.

B.S. Rao et al. [8], In this investigation, experimental studies have been carried out in three sinusoidal corrugated plate heat exchangers using water and 10% glycerol solution as test fluids. The plate heat exchanger is fabricated with two stainless steel sheets having a thickness of 1 mm. These sheets are welded together to form a corrugated test channel having a clearance of 5 mm and of length 30cm. Three such plate heat exchangers have been fabricated with corrugation angles of 30, 40 and 50 degrees. The experiments have been conducted on a range of 0.5 lpm to 6 lpm through the channel and the pressure drop data has been collected and analyzed.

M.C. Winkler [9], this thesis deals with the analysis of corrugated laminates under globally homogeneous deformation states. The models presented within this work are valid for the undisturbed regions of large structures where it can be assumed that edge effects and other stress concentrations are decayed. In agreement with these assumptions the local strains and stresses remain constant along the direction transverse to the corrugations which is a generalized plane-strain state. This allows that only an elasticity solution dependent on the other two directions has to be determined. If the geometry of corrugated laminates as well as the local displacements, strains and stresses is periodic in nature, it is sufficient for the determination and investigation of these quantities to consider only one representative unit cell. The homogenization of the corrugated laminate as a substitute plate is based on this model. The determination of the entries of the substitute plate matrix is built on the consideration of six load cases. With the substitute plate model the calculation cost can be reduced drastically in comparison to a numerical model of the complete structure. Based on this modeling approach two different models are presented. The first model uses the linear thin-shell theory of Sanders. The kinematics and the equilibrium equations from shell theory can be simplified for corrugations consisting of circular arcs due to the constant curvature. The combination of these equations with the constitutive equations of the Classical Lamination Theory and the application of the generalized plane-strain formulation gives three differential equations for the displacements which are the basis for the modeling of the corrugated laminates. By applying appropriate boundary, continuity and periodicity conditions the solution for displacements can be determined. The results can then be used to obtain strains, stresses, deformation limits and substitute stiffness matrix entries. For specially orthotropic laminates, where a symmetric and balanced cross ply laminate is the best-known laminate lay-up, it is even possible to derive closed-form solutions. For more complex laminate lay-ups and other corrugation geometries, the equations of the analytical model have to be solved numerically. The second model uses a two-dimensional continuum formulation implemented by means of the Finite Element Method. A special Finite Element model is developed which allows the limits of the analytical model to be overcome so that thick-walled structures and more general corrugation geometry can be calculated. Similar to the analytical model the generalized plane-strain formulation, boundary and periodicity conditions are used to obtain displacements, strains, stresses and substitute stiffness matrix entries. Both models are verified with the help of shell or solid models built with a commercial Finite Element software package. Furthermore, anisotropy effects only appearing with the Finite Element model and the influence of the thickness-to-radius ratio on the applicability of the analytical model are discussed. Based on these models the influence of the geometry and the orientation of unidirectional laminates on the substitute stiffness matrix entries, the realizable anisotropy and the deformation limits is investigated. For the corresponding parameter studies a high modulus carbon fibre reinforced epoxy composite material is used. Furthermore, the influence of the corrugation geometry on the anisotropy and the substitute stiffness matrix entries is determined. For the experimental part corrugated laminates made of a glass-fibre reinforced epoxy composite material were manufactured. The produced laminates were used to investigate the structural behaviour in the compliant direction. Corresponding tests with a load cycle including tensile and compressive load with two different sets of boundary conditions and with two different panel lengths were conducted. Comparisons of the experimental results to the substitute models, Finite Element models using the substitute plate approach and detailed Finite Element models analyze the applicability of the developed models. The error analysis investigates the influence of several parameters on the experimental results and on the predicted values of the models. In the final part of the thesis the results for the substitute stiffness matrix entries of the analytical model are compared to other analytical models. The comparison makes it possible to check the results and to detect differences of the stiffness expressions which are commented. Finally, aspects like edge effects or geometrical nonlinearities which can be critical for the application of the substitute models are discussed.

L.L. Yan et al. [10], All-metallic corrugate core sandwich panels as primary loading structures may rapidly soften under compressive loading due mainly to core member buckling once the peak compressive stress is reached, resulting in reduced load carrying capability. Inserting close-celled aluminium foam into the corrugate core has been envisioned as a feasible way to enhance the load capacity. The enhancement due to foam filling were firstly explored experimentally under quasi-static out-of-plane compression and the underlying mechanisms subsequently numerically studied using finite element simulations. The foam filled corrugated panel was found to have strength and energy absorption much greater than the sum of those of an empty corrugated sandwich panel and the aluminium foam alone. It was demonstrated that the core members in the foam-filled panel were considerably stabilized by the filling foam against lateral deflection. In particular, the elastoplastic buckling wavelength of the core members was significantly reduced and the transition from axial deformation to bending of the core member was much delayed, both of which contributing to the enhanced strength and energy adsorption capability of the foam filled panel.

Jeongho Choi et al. [2], the objective is to show a possibility of corrugated wire mesh laminate (CWML) structure for bone application. CWML is a part of open-cell structures with low density and high strength built with bonded mesh layers. Specimens of CWML made of 316 stainless steel woven meshes with 0.22 mm wire diameter and 0.95 mm mesh aperture, bonded by transit liquid phase (TLP) at low temperatures, were fabricated and tested under quasi-static conditions to determine their compressive behaviour with varying numbers of layers of the sample. The finite element software was used to model the CWML and studied their response to mechanical loading. Then, the numerical model was confirmed by the tested sample. Consequently, CWML specimens were reasonably matched with the human tibia bone ranged over apparent density from 0.05 to 0.08 g/cm3 in Young's modulus and from 0.05 to 0.11 g/cm3 in compressive yield strength. The CWML model can have the potential for bone application.

Ranga Raj R et al. [11], At present, composite materials are mostly used in aircraft structural components, because of their excellent properties like lightweight, high strength to weight ratio, high stiffness, and corrosion resistance and less expensive. In this experimental work, the mechanical properties of laminate, this is reinforced with stainless steel wire mesh, aluminium sheet metal, perforated aluminium sheet metal and glass fibres to be laminate and investigated. The stainless steel wire mesh and perforated aluminium metal were sequentially stacked to fabricate, hybrid composites. The aluminium metal sheet is also employed with that sequence to get maximum strength and less weight. The tensile, compressive and flexure tests carried out on the hybrid composite. To investigate the mechanical properties and elastic properties of the metal matrix composite laminate of a material we are using experimental test and theoretical calculation. The experimental work consists of Tensile, compressive and flexural test. The expectation of this project results in the tensile and compressive properties of this hybrid composite it is slightly lesser than carbon fibres but it could facilitate a weight reduction compared with CFRP panels. So this hybrid laminates composite material offering significant weight savings and maximum strength over some other GFRP conventional panels.

Xin Li et al. [12], corrugated sandwich panels are widely used in various fields because such panels have lower density, easier fabrication methods and higher strength compared with monolithic plates. In this study, the dynamic response of corrugated sandwich panels under air blast loading was investigated using a ballistic pendulum system. Two configurations of the specimen were considered. The residual deflection of the back face sheet and the deformation/failure modes of the sandwich panel under different impulse levels were analysed. Finite element simulations were performed by using AUTODYN. The deformation process and energy absorption of the face sheets and the core were investigated in the numerical simulation.

Viet Phuong Bui et al. [13], this paper presents the characterization of electromagnetic (EM) performance of conductive composite laminate in consideration for aeronautic design. Novel nanocomposite resin was prepared by incorporating nanofillers into neat epoxy, resulting in remarkable improvement of its electrical conductivity. The planar structure of conductive composite laminate, which consists of 33 layers of woven fabric carbon fibre sandwiched in the nanocomposite, was then fabricated under the optimal conditions offering many times higher conductivity than the composite laminate using neat resin. Simulations of newly-developed composite laminate exposed to lightning strike were performed. The comparative studies show that conductive composite laminate provides better lightning protection property than composite laminate with epoxy resin. The simulated shielding effectiveness of the composite panel is in good agreement with measured results in both S and X microwave bands. The shielding effectiveness of the conductive composite laminate characterized at the frequency above 1 GHz is less than 10% different from that of conventional composite with copper wire mesh on the outer layer currently-used in aerospace industry. The result of this study shows promising aspect in the EM design using nanostructured composite laminate.

C. Thill et al. [14], composite corrugated structures are known for their anisotropic properties. They exhibit relatively high stiffness parallel (longitudinal) to the corrugation direction and are relatively compliant in the direction perpendicular (transverse) to the corrugation. Thus, they offer a potential solution for morphing skin panels (MSPs) in the trailing edge region of a wing as a morphing control surface. In this paper, an overview of the work carried out by the present authors over the last few years on corrugated structures for morphing skin applications is first given. The second part of the paper presents recent work on the application of corrugated sandwich structures. Panels made from multiple unit cells of corrugated sandwich structures are used as MSPs in the trailing edge region of a scaled morphing aerofoil section. The aerofoil section features an internal actuation mechanism that allows chord wise length and camber change of the trailing edge region (aft 35% chord). Wind tunnel testing was carried out to demonstrate the MSP concept but also to explore its limitations. Suggestions for improvements arising from this study were deduced, one of which includes an investigation of a segmented skin. The overall results of this study show that the MSP concept exploiting corrugated sandwich structures offers a potential solution for local morphing wing skins for low speed and small air vehicles.

Ismet Kutlay Odaci et al. [15], an aluminium (1050 H14) multi-layer corrugated structure composed of brazed 16 trapezoidal zigzag fin layers was direct impact tested above the critical velocities for shock formation using a modified Split Hopkinson Pressure Bar. The experimentally measured stress-time histories of the cylindrical test samples in the direct impact tests were verified with the simulations implemented in the explicit finite element code of LS-DYNA. The quasi-static experimental and simulation deformation of the corrugated samples proceeded with the discrete, non-contiguous bands of crushed fin layers, while the dynamic crushing started from the proximal impact end and proceeded with a sequential and in-planar manner, showing shock type deformation characteristic. The experimental and numerical crushing stresses and the numerically determined densification strains of the fin layers increased with increasing impact velocity above the critical velocities. When the numerically determined densification strain at a specific velocity above the critical velocities was incorporated, the rigid-perfectly-plastic-locking idealized model resulted in peak stresses similar to the experimental and simulation mean crushing stresses. However, the model underestimated the experimental and simulation peak stresses below 200 m s-1. It was proposed, while the micro inertial effects were responsible for the increase of the crushing stresses at and below subcritical velocities, the shock deformation became dominant above the critical velocities.

Yuying Xia et al. [16], the design of the skins has been identified as a major issue for morphing aircraft wings. Corrugated laminates provide a good solution due to their extremely anisotropic behaviour. However, the optimal design of a morphing aircraft requires simple models of the skins that may be incorporated into multi-disciplinary system models. This requires equivalent material models that retain the dependence on the geometric parameters of the corrugated skins. An analytical homogenization model, which could be used for any corrugation shape, is suggested in this paper. This method is based on a simplified geometry for a unit-cell and the stiffness properties of original sheet. This paper investigates such a modeling strategy and demonstrates its performance and potential.

Maria Sabrina Sarto et al. [17], an effective-layer model is proposed to predict the EM shielding performances of metallic wire grids typically used as protective layers in carbon fibre-reinforced composite laminates for aeronautical applications. The model is valid over a wide frequency range and it takes into account the field penetration through the grating. The shielding performance of the wire grid is estimated by means of the average shielding effectiveness, which represents the response of the material to an incident plane wave having both transverse-magnetic and transverse-electric polarizations. The proposed model is validated by comparison with experimental data, which demonstrates its validity over a wide frequency range, up to 18 GHz.

Francesco Previtali et al. [31], in this paper, a morphing-wing concept based on compliant ribs is considered as a replacement for conventional ailerons and its performance is investigated. The roll performance of the three-dimensional morphing-wing solution for different design speeds and under structural and strength constraints is analyzed. The design approach uses optimization techniques and considers the three-dimensional aero structural behaviour. The results show the possibility of producing sufficient roll control authority with a morphing solution, thus replacing conventional ailerons up to a design speed of 250 Km/h. In a further step, the weight of the system as a function of the produced rolling moment is compared with the one of a conventional system. The obtained relations offer an estimation of the weight penalties associated with morphing. This estimation can be useful in the preliminary design of morphing aircraft.

Xiaobo Gong et al. [30] This work presents a variable stiffness corrugated structure based on a shape memory polymer (SMP) composite with corrugated laminates as reinforcement that shows smooth aerodynamic surface, extreme mechanical anisotropy and variable stiffness for potential morphing skin applications. The smart composite corrugated structure shows a low in-plane stiffness to minimize the actuation energy, but also possess high out-of-plane stiffness to transfer the aerodynamic pressure load. The skin provides an external smooth aerodynamic surface because of the one-sided filling with the SMP. Due to variable stiffness of the shape memory polymer the morphing skin exhibits a variable stiffness with a change of temperature, which can help the skin adjust its stiffness according different service environments and also lock the temporary shape without external force. Analytical models related to the transverse and bending stiffness are derived and validated using finite element techniques. The stiffness of the morphing skin is further investigated by performing a parametric analysis against the geometry of the corrugation and various sets of SMP fillers. The theoretical and numerical models show a good agreement and demonstrate the potential of this morphing skin concept for morphing aircraft applications. We also perform a feasibility study of the use of this morphing skin in a variable camber morphing wing baseline. The results show that the morphing skin concept exhibits sufficient bending stiffness to withstand the aerodynamic load at low speed (less than 0.3 Ma), while demonstrating a large transverse stiffness variation (up to 191 times) that helps to create a maximum mechanical efficiency of the structure under varying external conditions.

C. Thurnherr et al. [18], corrugated laminates have highly anisotropic stiffness properties. Therefore, they are interesting candidates for flexible skins. The geometrically non-linear stiffness response of corrugated sheets is crucial for applications with large deformations. The present paper analyzes the governing mechanisms that drive the non-linear tensile behaviour and suggests a model to analyze corrugated structures. The mechanical response mainly depends on the geometry such as amplitude and thickness of the corrugation and the material properties. The proposed model calculates the mechanical response based on a simplified model consisting of rods and discrete torsional springs. It is verified by comparison with non-linear structural analysis with FEM and experimentally validated by using samples manufactured by 3D printing. The paper also presents a parametric study investigating the influence of the geometry on the non-linear geometry and we identify the limits of linear approximation of the structural response of corrugated laminates.

Joachim L. Grenestedt et al. [19], compression wrinkling of composite sandwich panels with corrugated skins was investigated numerically, analytically and experimentally. Semi-circular and sine-wave shaped corrugations were studied. The corrugations significantly increased wrinkling strength when compared with equal mass flat panels. Semi-circular corrugations proved to be highly preferable to sine-wave shaped corrugations due to localized buckling in the latter. Over 40 fibre glass and foam core sandwich specimens were manufactured with semi-circular skin corrugations. These specimens were tested to failure, providing confirmation of the numerical and analytical results.

Joshua M. Lister et al. [20] this study will present the Experimental, numerical and analytical characterizations of composite sandwich structures needed to optimize structure design. In this study, the effects of varying honeycomb core ribbon orientation and varying face sheet thickness's have on the flexural geometry of honeycomb sandwich structures was investigated. Honeycomb sandwich panels were constructed using Hexcel 6367 A250-5H carbon fiber face sheets and Hexcel Nomex HRH-10-1/8-5 honeycomb cores. The mechanical properties of the constituent materials were discovered experimentally using ASTM standards and theoretical models using honeycomb mechanics and classical beam and plate theory are described. A failure mode map for loading under three point bending is developed from previous works by Triantafillou and Gibson26, showing the dependence of failure mode on face sheet to core thickness and honeycomb core ribbon orientation. Beam specimens are tested with the effects of Honeycomb core ribbon orientation and unequal face sheet thickness's examined. Experimental data sufficiently agrees with theoretical predictions. A finite element model was developed in ABAQUS/CAE to validate experimental and analytical analysis and produced agreeable results. Optimal bending stiffness and strength with respect to minimum weight was analyzed. The results reveal an important role core ribbon orientation has in a sandwich beam's bending geometry79, and design of unequal ply count face sheets can produce higher stiffness to weight ratios than conventional symmetric sandwich structures of similar weight when subjected to a single static load.

J. Tian et al. [21] this paper presents a combined experimental and theoretical study on the thermal–hydraulic performance of a novel type of periodic textile cellular structure, subjected to forced convection using both air and water as a coolant. The samples were fabricated as sandwich panels, with the textile cores bonded to two solid face-sheets using a brazing alloy. These efficient load supporting sandwich structures can also be used for active cooling. The effects of cell topology, pore fraction and material properties (high thermal conductivity copper or low thermal conductivity stainless steel) on both coolants flow resistance and heat transfer rate were measured. The flow friction factor is found to depend mainly on the open area ratio in the flow direction (which is dependent upon cell topology and pore fraction), whilst the amount of heat transferred is dependent upon solid conductivity, pore fraction and surface area density. Analytical models were used to develop predictive relations between both the pressure loss and heat transfer performance for different textile geometries. Good agreement between the predictions and measurements were obtained. Due to high thermal capacity of water, it was found that the model for water cooling must account for the additional contribution due to thermal dispersion. The dispersion conductivity was found to be related to coolant property, local flow velocity, wire diameter and pore fraction. Finally, the thermal performance of brazed woven textiles is compared with other heat exchanger media, such as open-celled metallic foams and louvered fins.

K.M. Liew et al. [22] this paper presents a geometrically nonlinear analysis of stiffened and un-stiffened corrugated plates using a mesh free Galerkin method that is based on the first-order shear deformation theory (FSDT). The strains are assumed to be small, and the corrugated plates are geometry approximately as equivalent orthotropic plates. The large deflection theory of von Karman is adopted in the nonlinear analysis of the orthotropic plate, and the equivalent flexure properties of the orthotropic plate are derived. Both the equivalent flexure and extensional properties are employed in the nonlinear analysis. The stiffened corrugated plates are analyzed as stiffened orthotropic plates, in which the stiffeners are geometry as beams and fitted to the equivalent orthotropic securing the cargo in place. The numerical model is developed as a design tool for investigating the trends associated with new or existing bags. Modeling considerations are outlined with an emphasis on the material properties of paper. The effects of material, geometry and boundary condition non-linearity are discussed. The development of a stable generic model is described in detail. The effect of time scale factor, load application, analysis time, global damping, mesh refinement, Poisson's ratio and plate by implementing displacement compatibility conditions between the plate and the stiffeners. Because no mesh is required in the proposed method, the stiffeners can be placed anywhere on the plate, and changes to the positions of the stiffeners do not entail the re-meshing of the plate. To demonstrate the convergence and accuracy of the proposed method, several numerical examples are employed. The solutions that are computed by the proposed method are compared with precise solutions that are given by ANSYS using shell elements and with the results of other research work.

S. P. Kondapalli et al. [23], Design of Experiment (DOE) is one of the extensively used methods for experimental study of many manufacturing processes in engineering. DOE is a statistical approach in which a mathematical model is developed through experimental runs. Thus, possible output can be predicted based on the input parameters of the experimental setup. The present study reviews current literature on DOE techniques that have been employed for various welding processes with particular emphasis on the application of Taguchi method on fusion arc welding processes namely, gas tungsten arc welding and plasma arc welding.

Martin Philip Venter et al. [29] this thesis relates to the development of a numerical model for the paper dunnage bag. Dunnage bags all the voids between cargo, thus

mass scaling are investigated. The development of a representative model follows, where the process of including the inflation valve, glued seam lines, void constraint size and material model are discussed. Physical testing was performed, and the results were used to validate the numerical model developed. The shape of the model matched that of the physical samples, and the restraining force produced by the bag was found to be within 7% of the tested values.

Table: 5.1 Literature Review

Sr. No	Year	Author	Publication	Work	Fabrication Method	Test	Material	Parameters
1	2015	I. DAYYANI	ELSEVIER	Review of CWML for Morphing wings	-	-	-	-
2	2013	JEOGHO CHOI	ELSEVIER	Elasticity of Corrugated wire mesh	TLP Soldering by using Tin alloy	Uniaxial Compression test	316SS	Wire diameter Opening space (aperture)
3	2007	P. ISAKSSON	ELSEVIER	Shear correction factor for corrugated structures	Homogenised corrugated boards	Single and Three point bending test	Corrugated boards	Shear correction factor
4	2009	JEOGHO CHOI	World academy of science Engg.& Tech.	Methods for manufacturing of CWML	Lithobraze and Utectic solder technique	Uniaxial compression test	304 and 316 SST	Density Wire Diameter
5	2014	B.S.Rao	IJAET	Effect of corrugation angle on pressure drop	Welding	Heat exchanger test for viscous fluid	SS Sheets	Corrugation angle
6	2013	L.L. YAN	ELSEVIER	Compressive strength and energy absorption of CWML	Simple bonding method	Quasi static out plane compression strain test	Foam filled corrugated panel	Stress/stain relationship
7	2015	RANGA RAJ R.	IJERA	Experimental test of SS wire mesh, alluminium alloy with glass fibre rainforced composits	Simple bonding by using epoxy material	Tensile Compressive Flexural	SS, Alluminium Alloy and glass fibers	-
8	2016	C. Thurnherr	ELSEVIER	Non linear stiffness response of CWML in tensile loading	Fussed deposition modeling (FDM)	Tensile test	3D Printed model	Amplitude Thikness

5.2 Major Findings of literature:

1. Structures of Corrugated wire mesh Laminates:

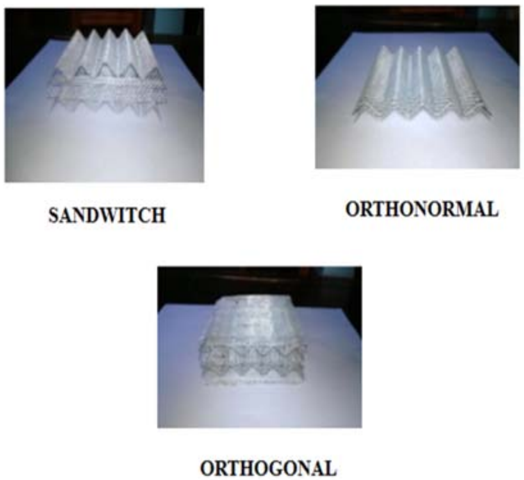

Fig. 5.1 CWML structures

2. Fabrication Techniques
3. Parameters affecting on strength
4. Types of tests for Experimentation
5. Optimization techniques

6. METHODOLOGY

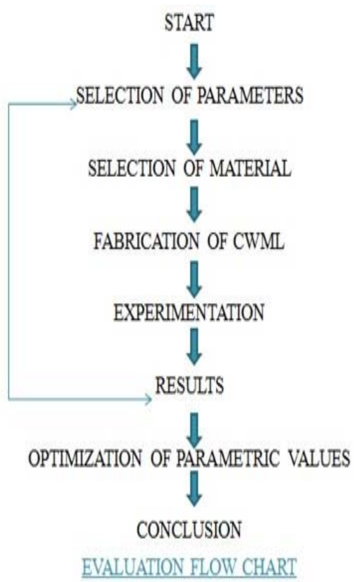

Fig. 6.1 Flow Chart

6.1 Selection of PARAMETERS:

In Taguchi's methodology, all factors affecting the process quality can be divided into two types: control factors and noise factors [7]. The signal factors are material of the wire mesh, the wire diameter, the opening width, number of layers, number of corrugations and corrugation parameters such as the corrugation height and the base angle which can be altered to provide a wide range of transverse stiffness and strength to the CWML [1]. Previous studies employed samples in which the corrugations were created using the same base angle. The selected signal factors are corrugation angle, laminates structure and number of corrugated layers while noise factors are surrounding temperature, moisture content in air, acidic environment, humidity etc which often cannot be eliminated and causes variation in the output. The repeatable and uniform corrugations are obtained if sheets are prepared using 45° triangular profile [8]. Hence levels of corrugation angles (φ) can be taken as 40°, 45°, 50° and below these range load carrying capacity of CWML structure decreases and above the range there are chances of breaking wire mesh at the centre of corrugation as well as weight also increases. Typically, alternating layers of the CWML may be arranged orthogonally so that the high stiffness provided by the corrugation is available in both directions [1]. Hence levels of laminates structure can be taken as sandwich, orthonormal and orthogonal. For a given wire diameter, minimizing the number of layers or the number of corrugation waves is likely to make structure less capable of carrying load. Therefore, from the point of view of increasing mechanical strength and stiffness, it may be desirable to have multiple layers of wire mesh with multiple corrugations in each layer and on the other side increasing no of layers increases the weight of the structure. Since our aim is to obtain a high strength light weight structure number of corrugated layers may be 2, 3 and 4.

6.2 Fabrication:

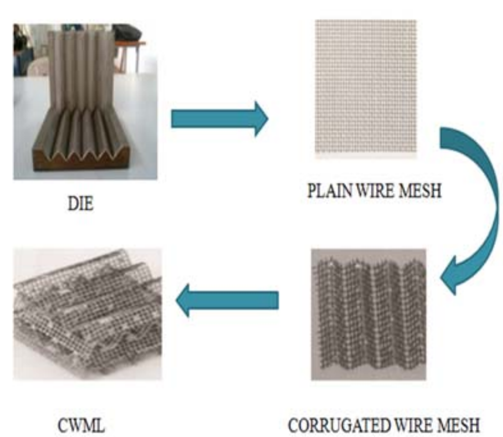

Fig. 6.2 Fabrication Process

The fabrication of Corrugated Wire Mesh Laminates is a complex process. The Starting material is a plain or woven wire mesh. The first step in the fabrication of CWML is to create the corrugations, which is done by subjecting the plain mesh to a die and punching process. Single layers of the corrugated mesh are then cut to size and arranged in their desired sequence of lamination. The final and major step in the fabrication process is the bonding of the different layers of the CWML to each other using techniques such as welding, adhesive bonding, brazing or soldering which involve high temperature processing [4]. The wire mesh is made up from any aluminum alloy which is commonly used as core material for lightweight sandwich constructions in mechanical, automotive, marine and aerospace engineering having smallest wire diameter with minimum aperture (values of wire diameter, aperture and grade of alloy may be selected as per availability in the market). There is requirement of bonding material. The die and punch design is required according to corrugation required for the study. The plain wire mesh is fed through this pair of die and punches to create corrugations in them. The samples of corrugated wire mesh laminates were prepared according to the combination given in Taguchi's L9 orthogonal array.

6.3 Experimentation:

All the fabricated samples have to measure for length, height and width. The samples are nominally square with a side length in corrugation direction (Lx) and perpendicular direction (Ly) and a varying corrugation height (Ho) according to different corrugation angles and having five corrugation waves in each wire. Diameter of wire (d) and opening width (w) of wire mesh have to select as per the availability.[3] The nine samples of corrugated wire mesh laminates with three different combinations of corrugation angle, laminates structure and no of layers will be tested.[4] Compression, tensile or bending test of each specimen of corrugated wire mesh laminates will be conducted at room temperature using universal testing machine. Validation of results is important. By using ANOVA we can calculate the results and verify the analytical and practical results. [22]

7. OPTIMIZATION TECHNIQUES

7.1 Design and analysis of experiments:

Design of experiment is a powerful statistical method for determining the unknown properties of the operating parameters in the experiment process and for analyzing and modeling the interaction among the factors. The classical experimental design methods are too complex and not easy to use. Additionally, a large numbers of experiments have to be carried out when the number of operating parameters increases. Therefore, the factors causing variations should be determined and checked under laboratory conditions. These studies are considered under the scope of off-line quality improvement. [13]

7.2 Taguchi's method:

There are various methods used for improving the quality in variety of industries. Taguchi method is one of the best optimization technique to achieve high quality without increasing cost. It is a simple, systematic and powerful method to increase the quality. The advantage of this method is to reduce both product cost and number of experiments required. Mathematical and statistical techniques are combined in Taguchi method. In this research work, Taguchi's method is used for improving the effectiveness in the cooling tower. Two important tools employed in Taguchi's method are signal to noise ratio (S/N ratio) and orthogonal arrays (OA). In Taguchi method, first, significant process parameters and their levels are selected. The ranges of these parameters were selected on the basis of preliminary experiments conducted by using one variable at a time approach. In this research work, three control factors and three levels are chosen for analyzing the effectiveness. [13]

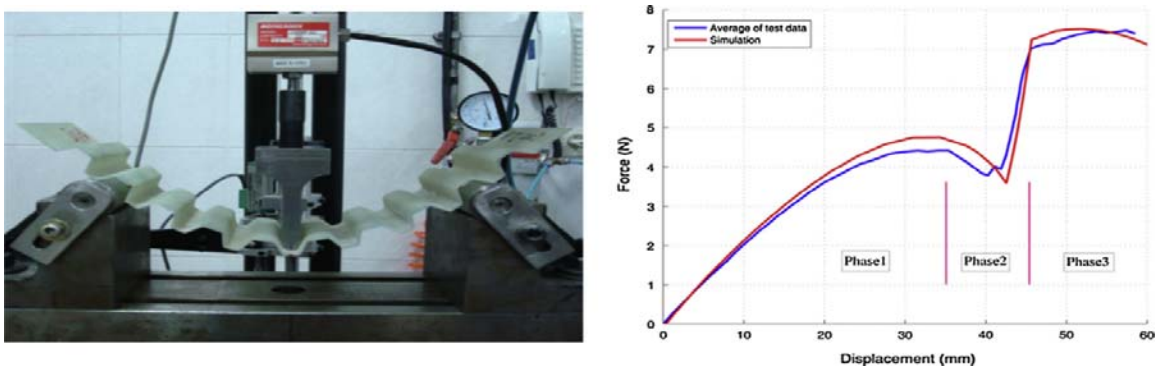

Fig. 6.3 Testing Machine and sample graph

7.3 Selection of Orthogonal Array (OA)

In Taguchi method, experimental analysis is based on orthogonal array. Orthogonal array is used to minimize the number of experiments, by which quality characteristics are examined. The appropriate OA is selected on the basis of total degrees of freedom required. By using number of factors, number of levels of each factor and number of interactions DOF is determined. In this research work, the interaction effect between the process parameters is not considered. The degree of freedom for three levels is 2 (DOF = number of levels - 1). The required total DOF for three factors and three levels is 6 (3 x (3 - 1) = 6).In Taguchi method, the total DOF of selected OA must be greater than or equal to the total DOF required for the experiment. Hence L9 OA having eight DOF is selected in this research work. [14]

7.4 Signal to Noise ratio

In Taguchi method, signal to noise ratio (S/N ratio) is employed to analysis the quality characteristics of the product or process parameters. It is also called as statistical measure of performance. It is the ratio of the mean (signal) to the standard deviation (Noise). Regardless of the category of the quality characteristic, process parameter settings with the highest S/N ratio always yield the optimum quality with minimum variance. The following three types of S/N ratios are considered to be standard and are widely applied in Taguchi method.

(1). Smaller is better

(2). Nominal is the best

(3). Larger is better

As the objective of this study is the maximization of cooling tower effectiveness, LB is chosen. Where n is the number of measurements and y_i the parameters being measured through the experiments. The average values of effectiveness mean and S/N ratios for each parameter at different levels are plotted. Based on the S/N ratio larger is best (LB), gives higher effectiveness values. [14]

7.5 Analysis of Variance (ANVOA):

ANVOA is a method most widely used for determining significant parameters on response and measuring their effects. In the cooling tower performance, the major factor of the non-reproducibility is the controls the test facility and the cooling tower operating condition. In ANOVA, the ratio between the variance of the process parameter and the error variance is called as F-test. It determines whether the parameter has significant effect on the quality characteristics. This process is carried out by comparing the F-test value of the parameter with the standard value (F0.05) at the 5% significance level. If F-test value is greater than F0.05, the process parameter is considered significant. It can be seen that all factors are significant. [14]

7.6 Regression Analysis

By mean of regression and correlation analysis, the effect of process parameter on the quality characteristics of effectiveness measured. It is clear that statistical model can predict the effectiveness with sufficient accuracy depending on the obtained correlation coefficients (R_2= 96.6%) Predicted results obtained [14].

8. CONCLUSION

Corrugated structures have conspicuous impacts on the engineering applications due to their superior structural characteristics such as extreme anisotropic behaviour and high stiffness to weight ratio, mainly arising from their geometric properties. In this paper a detailed review of the literature on corrugated structures was presented. The paper described different types of corrugated structures, their specific characteristics and their categorised applications. Extending their applications, innovation and developments of these structures were discussed in terms of introducing further geometric parameters and combining different material properties.

It gives a comprehensive set of analyses about the mechanics of these structures was presented. The in-plane and out of plane stiffness of the corrugated panels were reviewed in details through experimental, numerical and analytical homogenisation analysis. The most common methods to analyse buckling and vibration of corrugated sheets were discussed such as FEM and combination of their homogenised models with the classic shell and plates methods. Although the latter methods had the advantage of simplicity, they could not account for local effects and higher modes, within the structure of the corrugation. The complex deformations occurring in corrugated structures during impact such as: internal buckling, contact friction and plastic deformation were discussed in terms of energy absorbing capability of these structures. The fatigue assessment of the corrugated structural components subjected to cyclic loading was also reviewed. The result shows that the crack initiations and delamination were two main factors for the fracture of these structures. Finally the optimization problem as an important tool in the design of corrugated structures was discussed. A variety of optimization objectives were represented, where some of them had potential conflicting nature. This highlighted the importance of finding the best compromise situation in the multidisciplinary design problems.

The paper reviewed the use of corrugated structures in morphing applications. It highlighted the importance of a study which ensures that all likely aspects of the morphing corrugated skin will be considered and integrated into a complete analysis. Terms like specific boundary conditions, structural and aerodynamic loading configuration as well as the geometric and manufacturing constraints that each application poses are discussed. The aerodynamic performance in all these applications was reported highly dependent on the corrugation geometry and Reynolds number. The low fidelity analysis were found highly necessary for use in these system level analyses and optimizations, as they provided a feasible estimate of each design objective while keeping the computations efficient in terms of time and cost. The high fidelity analysis of the corrugated skins was required in validation of the initial results and modelling complex deformations.

This review shows that the level of maturity for morphing corrugated skins is yet low and for most of the concepts analyses such as: vibration and aero elasticity, buckling, impact, fatigue and fracture and chemical resistance, have not been so far noticed. Validation of the methods are necessary by using main affecting parameters of CWML on strength, stiffness etc.

AKNOLEDGMENT

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