LMAPR2020: Project 1
Increasing the stiffness of steel sheet

Presented by Group L:

Gad Omar

Vansnick François

Flat metal sheet limitations

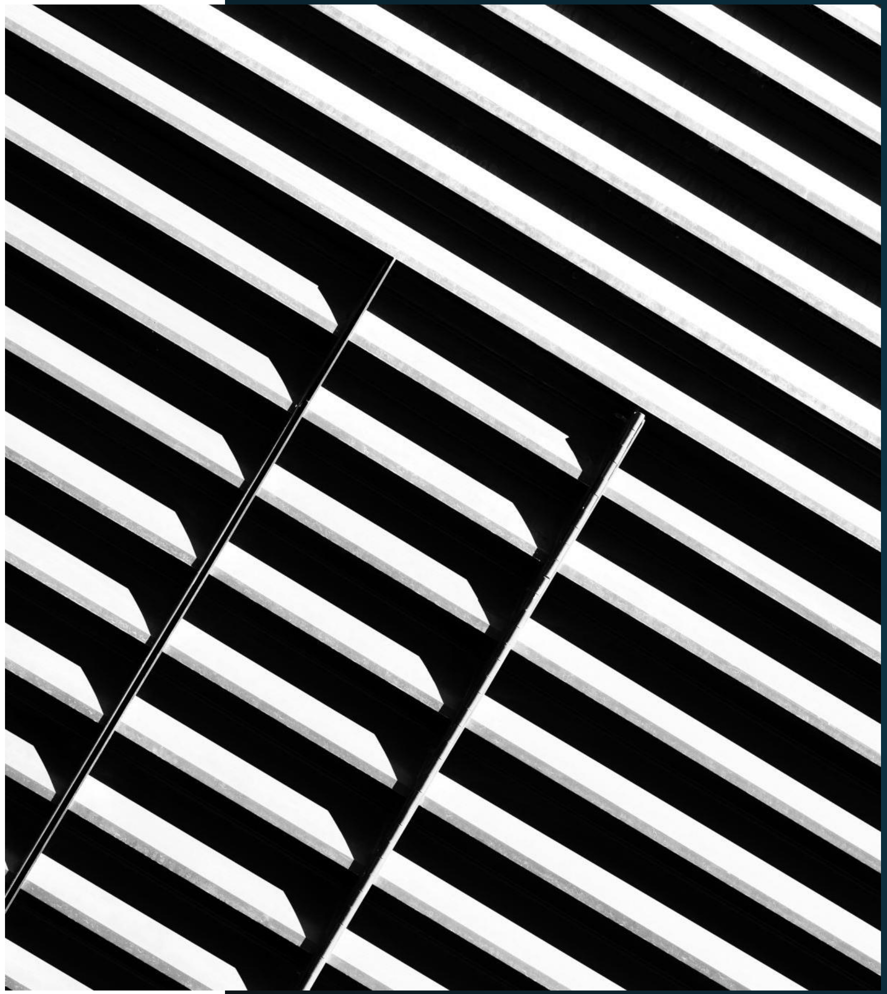
VIBRATION / NOISE

FLEX AND DEFORMATION

FATIGUE / CRACKS

Advantages of stiff metal sheet vs flat sheet

- Overall higher strength while keeping the same mass
- Better resistance to buckling and bending
- Easier to carry and store
- The structure allows for a quitter environment
- Can be lighter with the use of thinner sheets



Design Requirements for Stiffened Steel Sheet

Function: Steel sheet for stiffness-limited structures

Constraints: Profile limited to a maximum deviation ± 5 times the sheet thickness from flatness

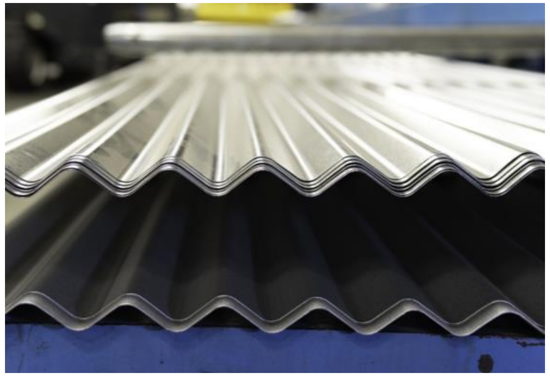
Cheap to manufacture

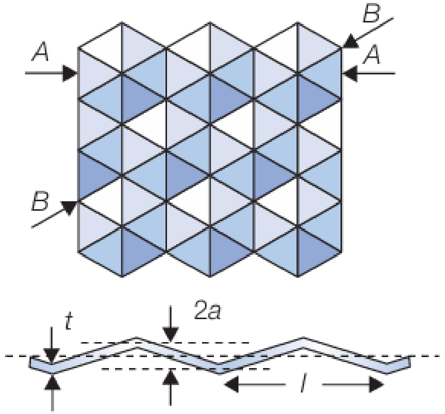
Objective: Maximize bending stiffness of sheet

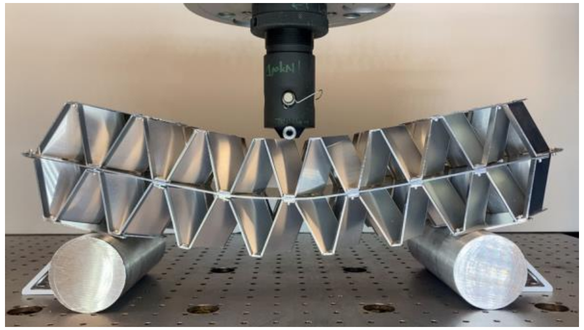
Free variables: Section profile

Stiffened sheets manufacturing Techniques

- Corrugations
  - Waves in one direction
  - By Roll or Press forming
- Flanges & Folds
  - Local edge stiffeners
  - By Folding, Bending or Press forming
- Dimples or Embossing
  - Small edge folds or ribs to locally increase stiffness
  - Folding, Roll or Press bending
- Origami Folds
  - Geometric fold patterns that spread deformation
  - Laser cutting + folding



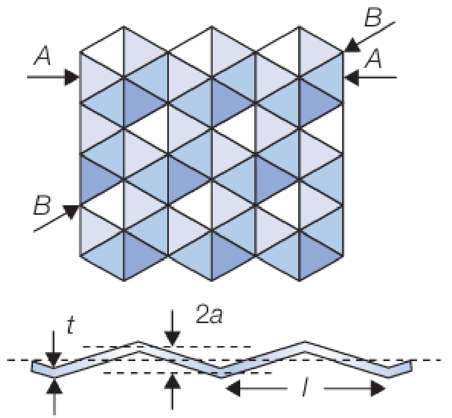




Solution : A hexagonal grid of dimples

- Stiffness is given by : $S = \frac{C_1 E I}{L^3}$
- Young's Modulus (E) is fixed by the material
- Second moment of Area (I) can be improved
- For a flat sheet : $I = \int_{-\frac{t}{2}}^{\frac{t}{2}} y^2 * b(y)\, dy = \frac{t^3}{12}$
- For the corrugated : $I \approx \frac{1}{12}(2a+t)^2 * t$

$$\phi_B^e = \frac{I}{I_0} \approx \frac{(2a+t)^2}{t^2}$$



Solution : A hexagonal grid of dimples

- Shape factor for fracture bending : $\phi_B^f = \frac{Z}{Z_0}$
- For the flat plate : $Z_0 = \frac{I_0}{y_m} = \frac{\frac{t^3}{12}}{\frac{t}{2}} = \frac{t^2}{6}$
- For the corrugated plate : $Z = \frac{I}{y_m} = \frac{\left(\frac{1}{12}(2a+t)^2 * t\right)}{(\frac{2a+t}{2})} = \frac{(2a+t)*t}{6}$

$$\phi_B^f = \frac{Z}{Z_0} \approx \frac{(2a+t)}{t}$$

Solution : A hexagonal grid of dimples

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- Increase bending stiffness and bending fracture resistance for the same mass
- Can be easily manufactured using cold rolling techniques

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- Bad stiffness distribution, only higher at the dimple peaks
- Risk of local buckling
- Non-negligible cost due to special forming tools
- May not look good for visible surfaces

Applications

AUTOMOTIVE

(BUMPERS ARMATURES, SEAT FRAMES, SIDE IMPACT BARS)

CONSTRUCTION

(WALLS, ROOFING, CYLINDRICAL SHAPES)

AIRCRAFT FUSELAGE SKINS

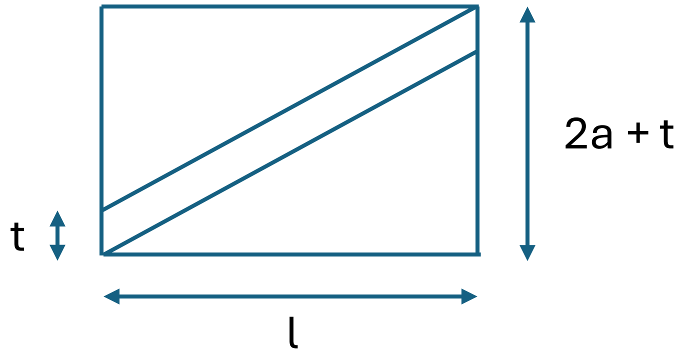
MANY LIGHTWEIGHT STRUCTURES APPLICATIONS

Conclusion

- Steel sheets are strong, affordable and available
- Stiffness can be improved using dimples, corrugations or folds
- Shape modifications adds no extra weight
- Used in many industries, not only for steel…

Question ?

Annexes

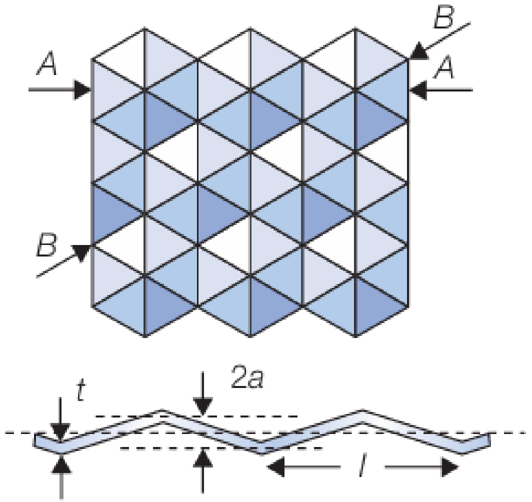


Pattern for calculation of the second moment of area

$$I = \underbrace{\frac{1}{12} l(2a+t)^3}_{\text{Rectangle}} - 2 \times \underbrace{\left[\frac{1}{36} la^3 + \frac{la}{2}\left(\frac{2a}{3} + \frac{t}{2}\right)^2\right]}_{\text{2 X Triangle}}$$

$$I = \frac{1}{12}\left(2a^3 + t^3 + 4a^2 t + 3at^2\right) \approx \frac{1}{12}(2a+t)^2 * t$$

Calculation of Shape factor for fracture bending



$$\Phi_B^f = \frac{Z_0}{2} \quad \Rightarrow \quad \begin{cases} Z_0 = \dfrac{I_0}{c_0} \\ Z = \dfrac{I}{c} \\ c = a + \dfrac{t}{2} \\ c_0 = a \end{cases}$$

$$\Phi_B^f = \frac{a+t}{t}$$