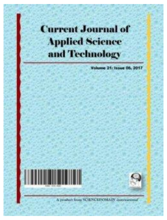

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End-of-life Vehicles Steel Sections Reclamation into Honeycomb Sandwich Panels

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Authors' contributions

This work was carried out in collaboration between all authors. Author ZTA designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors RHM, GSS and SBY managed the analyses of the study. Author ZTA managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Aims: Sustainable closed loop supply chain between vehicles industry and construction materials industry through exploiting of sections of end-of-life vehicles frames as steel cores of honeycomb sandwich panels. Such sections are attributed by high value-added because they are made of hot stamped steel sheets with good thicknesses by using matured manufacturing technology. Reclamation of steel sections can help reduce energy and material consumption and Co_2 emissions.

Study Design: Practical application of disassembly is followed by experimental work to prepare reclaimed steel cores honeycomb sandwich panels testing samples to study reliability and viability of such honeycomb through studying of mechanical properties and comparing reclaimed steel with recycle and virgin metals to find out energy and Co_2 emissions reductions of reclaimed end-of-life vehicle steel frames sections into honeycomb panels.

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Methodology: End-of-life vehicle frames are studied and disassembled to classify three suitable sections to be used as steel cores for honeycomb sandwich panels. Thin galvanized steel sheets are also used to cover the cores at the top and bottom as sandwich for both purposes of strengthen and decoration. Reclamation and testing routes are figured and mechanical properties data are recorded to be used for under load behavior analysis. Feasibility study of reclaimed sections honeycomb is based on energy and Co_2 emissions reductions through eco-comparison energy and Co_2 ratios based mitigation among reclaimed steel and recycled and virgin metals include steel, stainless steel and aluminium.

Results: End-of-life sections can be successfully reclaimed into honeycomb to substitute current consumption of paper, aluminium and stainless steel in field of construction materials which delivered with a reduction in energy consumption and Co_2 emission. By using these high value-added sections, mechanical properties of honeycomb can be enhanced to be more than enough for construction application. High levels of cut in both of energy and Co_2 emissions are obtained.

Conclusion: Reliable steel cores honeycomb sandwich panels can be produced to be used as construction material by exploiting of manufacturing technology and assembly techniques for reclamation. End-of-life sections are of high value-added and also can reduce using of new materials for making honeycomb as a sustainable manufacturing contribution.

Keywords: Steel cores honeycomb; end-of-life steel reclamation; vehicle frames reclamation; reclaimed honeycomb; scrap steel reclamation.

1. INTRODUCTION

Closed-loop production systems and closed-loop supply chains can be achieved using different approaches and strategies to contribute both of the reduction of negative environmental impacts and increase of economic benefits. Closed-loop production systems improve sustainability and lead to improvements in economic and environmental performance of an organisation. Sustainable development is recognised as a long-term oriented strategy to concern both current and future generations. Thus, it is crucial to combine short-term and long-term goals. For manufacturing to be sustainable development, long-term and short-term actions are required. But even long-term perspective is essential for manufacturing organisations to achieve sustainable development. However, analysis can show that the time perspective is taken rarely with emphasise on short-term thinking for sustainability but the need to focus on both long and short-term aspects is highly required [1]. Application of logical paths to find out economic concurrent engineering for end-of-life actions which facilitates reclamation of raw material is a trans-boundary closed loop supply chain to cut of energy and Co_2 emissions of two open supply chains one for manufacturer(vehicles industry) and another for remanufacturer(recent consumer)(construction material industry) as a sustainable manufacturing application. It is an incorporation of both of long term and short term thinking of sustainability through eco-design based remanufacturing [2]. This is highlighted through the work of Anastasiia Moldavska and Torgeir Welo where they conclude that: “However, we found only eight articles in this review to include end-of-life issues such as recycling, reuse, remanufacturing, etc. Also, only two articles use a closed-loop aspect in connection with the definitions; closed loop product life cycle (Lee et al., 2014) and closed loop supply chain (Abdullah et al., 2015).” [1]. Thus reclamation is one of the required activities within the frame work of remanufacturing at the end-of-life of the product to close the supply chain and predominate sustainable manufacturing. Power demand growth induces fossil fuels to be consumed increasingly which requires optimised management and development for sustainable utilisation of power [3]. Pollutes and particulate matter emissions are accompanied outputs for manufacturing activities due to their nature as power consumers [4]. End-of-life products of high value-added can be restored by remanufacturing and in accordance reclamation. This can help innovate the idea of reclamation of end-of-life vehicles steel frame sections into steel cores for honeycomb sandwich panels to apply ultimate form of recycling. Such frames are made of hot stamped steel with good thicknesses and they can withstand climate conditions to prevent rust and corrosion where coating and painting films are very powerful for protection and cannot be found easily in new structural steel sheets. Energy and material saves and pollution emissions reduction are some criteria to be applied for measuring feasibility of such sustainable manufacturing approach. This directive highly requires innovating great recycling value through planting

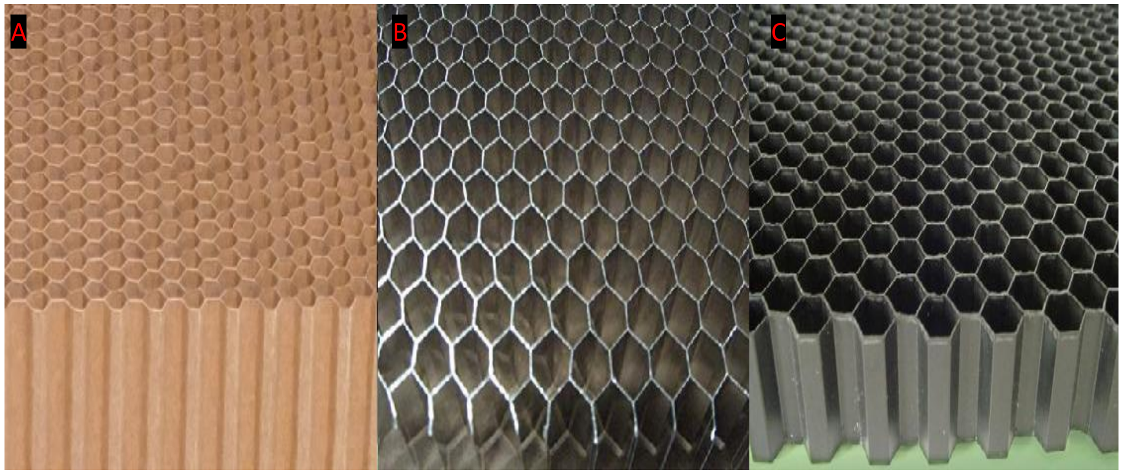

Fig. 1. Illustration of core material of honeycomb for construction application A (Paper), B (Aluminum) and C (Stainless Steel) [9]

potentials for reclamation and absolute remanufacturability through flexible assembly-disassembly mechanisms [5]. Honeycomb is valued structural composite material can deliver benefits of low weight, high stiffness, good durability and low production cost. Hexagonal honeycomb, double flex core, flex core and reinforced hexagonal core are of different configuration [6]. Paper, aluminium and stainless steel cores of honeycomb can be seen in Fig. 1, these various composites can be used for applications in field of construction engineering, scientific and industrial to be fulfilled powerfully. Outstanding aesthetic features are combined with fair mechanical properties of the cover sheets are being highly appreciated by designers, architects and planners to introduce honeycomb in their designs. Interior designs of the honeycomb are of perfect details and can be easily fabricated by using conventional manufacturing processes and can be used for a great variety of applications to become increasingly popular. Honeycomb composite sandwich panels are non-outgassing, non-particle shedding, anti-static, low density and non-combustible, so they are very suitable environmental composite materials for construction and furniture making applications. Honeycomb cores are divided into many sealed cells to restrain air circulation and greatly prevent the heat transmission and sound propagation in honeycomb sandwich panels. To provide better heat and sound insulations, honeycomb sandwich panels can be used for floors, supports, ceilings and partition to be delivered with function of good rating fire controlling. The interconnected honeycomb cores are uniformly distributed on the whole sandwich panel to play with cover sheets as single mechanism of good resistance for shearing, bending and buckling [7,8]. Reclamation based sustainability of triple-bottom line of economic, environmental and social developing criteria are required for growth of developing countries. Common landfill as treatment of end-of-life products can delay such growth so that technology, methodology and business oriented innovations are required to be developed as enablers for reclamation. This directly affects the energy footprint and the raw material consumption through closing both supply chain and product lifecycle by reclamation as a service to reach sustainable manufacturing [10].

2. STEEL CORES HONEYCOMB RECLAMATION TECHNOLOGICAL PATH

An eco-design idea can incorporate both of honeycomb for architecture application and closing the loop of supply chain of automotive industry for sustainable manufacturing to produce construction material of enough properties for ideal innovative and artistic ceiling, construction, claddings and filling. Reclamation is a powerful feedback tool to be used for developing eco-design innovation to produce more sustainable steel sections. Reclamation technological path of steel cores honeycomb sandwich panels is illustrated in Fig. 2, where manufacturing processes of shearing and drilling are used for frames disassembly, cut fit to size of cells and assembly holes of steel sections are followed by manual screws assembly to maintain, as can as possible, shape continuity and alignment of similarity to produce honeycomb steel cores. Complete honeycomb sandwich panel is assembly of formed grid of steel sections which are steels cores with new steel sheets at top and bottom by using universal adhesive for better appearance for decoration and increasing strength. This is concluded in Fig. 3 as an eco-design idea of reclamation of end-of-life steel sections into steel honeycomb panels illustration which is CAD model simulation where A(Core of Front Pillar), B (Core of Center Pillar) and C (Core of Roof Rail). Fig. 4 shows parts of passenger vehicle hulk frame and their names. End-of-life vehicle is disassembly by shearing to separate several sections to be used for honeycomb sandwich preparation, positions, where sections are taken, are shown in Fig. 5. The selected sections are cut into small cells of 50mm height that simulates honeycomb panels for construction application, Fig. 5. Since sections are of different shapes and thicknesses, Fig. 6, classification can recognise two sections, Front Pillar and Center Pillar, to be very close where cells have convergent recognition ratio which is height to biggest dimension at section plane ratio of (0.44) for (Front Pillar) and (0.49) for (Center Pillar) respectively. And both sections are of the same wall thickness of (2 mm).While the third section, (Roof Rail), is of recognition ratio of (0.37) and also of (1 mm) thickness. Six sheared sections are assembly by using screws of M8 size and holes are made through the sections to facility flexible assembly, Fig. 8.

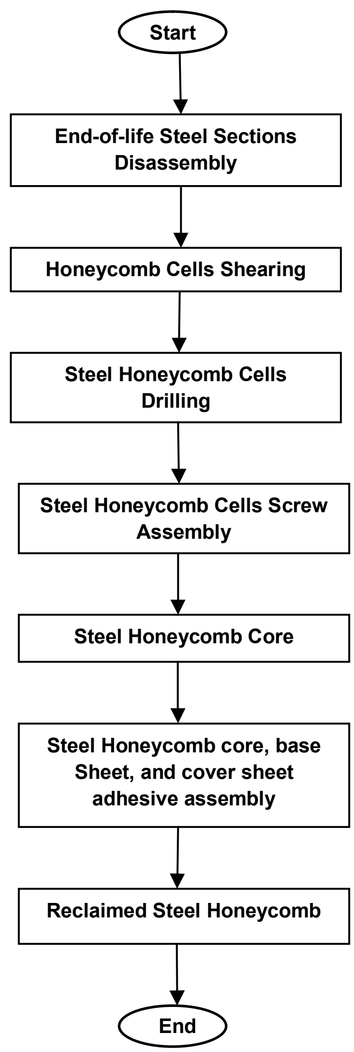

Fig. 2. Steel honeycomb reclamation technological path

Step1: Six sections are assembly to each other to produce core of Honeycomb	Step2:- Core is alignment on base of steel sheet	Step3: Core is covered with steel sheets

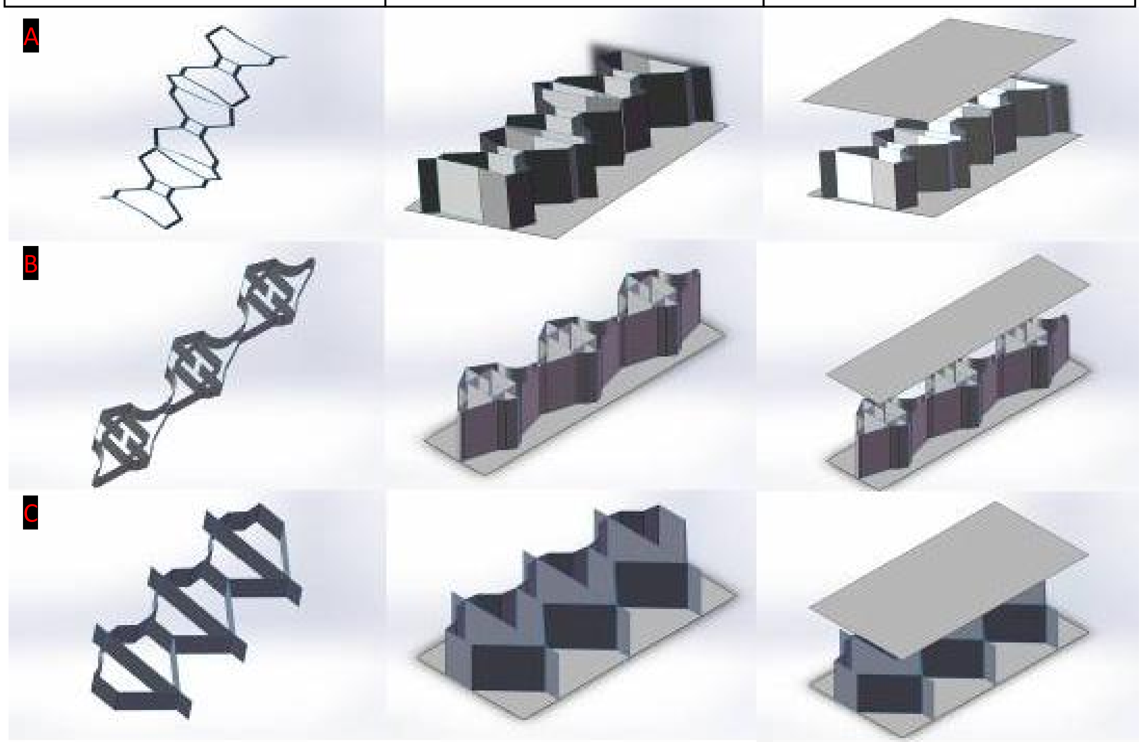

Fig. 3. Reclamation of end-of-life steel sections into steel honeycomb panels, eco-idea illustration, CAD model simulation, A (Core of Front Pillar) , B (Core of Center Pillar), and C (Core of Roof Rail)

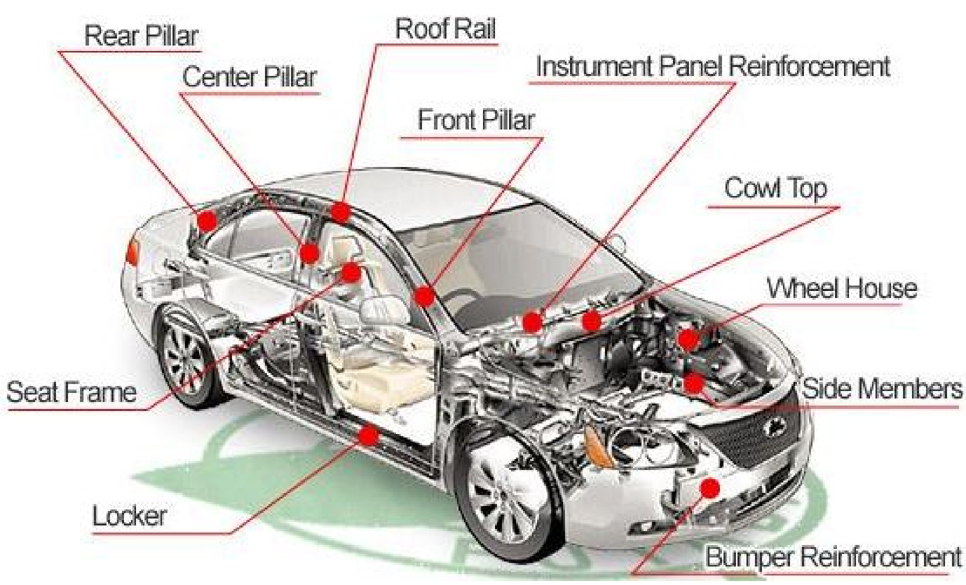

Fig. 4. Parts of passenger car frame and their names [11]

Fig. 5. End-of-life vehicle disassembly by shearing to separate several sections to be used for honeycomb sandwich preparation A (Center Pillar Section and Roof Rail Section), B (Front Pillar Section)

Fig. 6. Front Pillar (A), Roof Rail (B,C), and Center Pillar (D) disassembly by shearing to separate cells to be used for honeycomb sandwich preparation

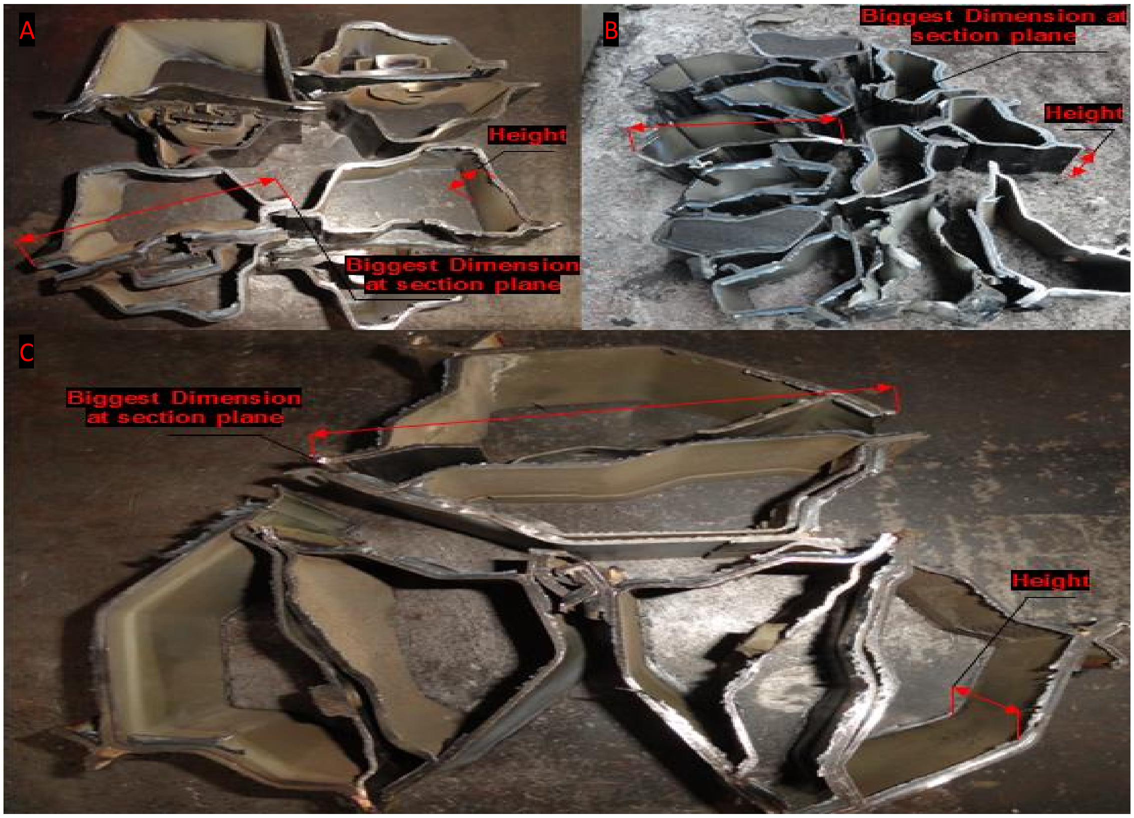

Fig. 7. Illustration of Height and Biggest Dimension at section plane of unit cell, A (Center Pillar Section), B (Front Pillar Section), C (Roof Rail Section)

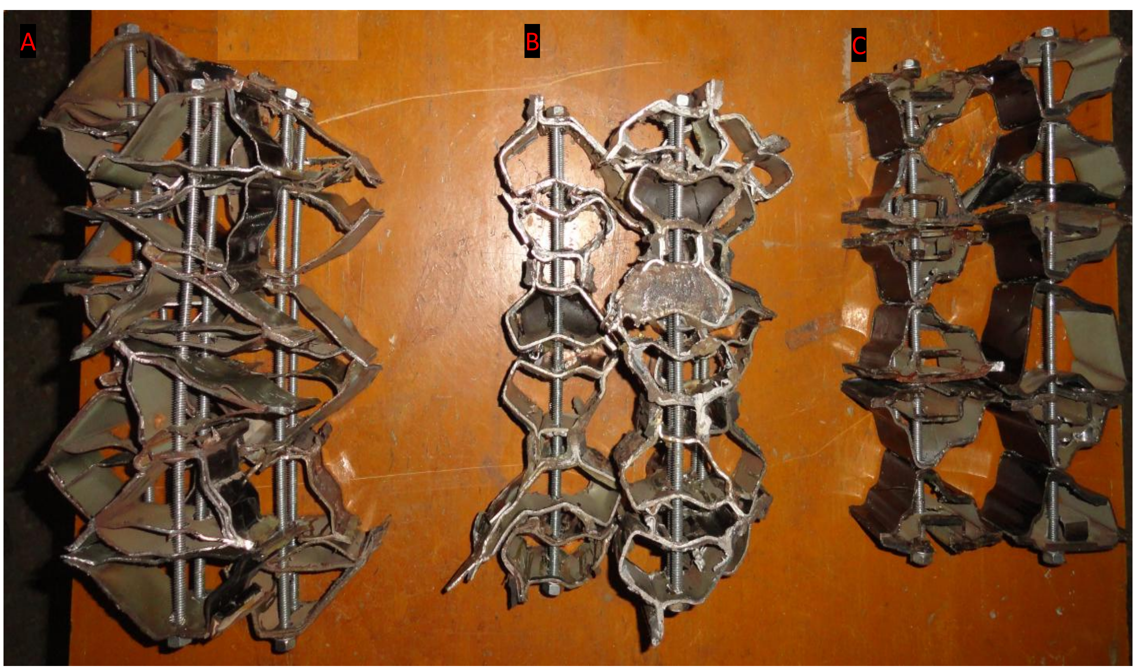

Fig. 8. Six Sheared Sections are assembly by using screws of M8 size and holes A (Roof Rail Section), B (Front Pillar Section), C (Center Pillar Section)

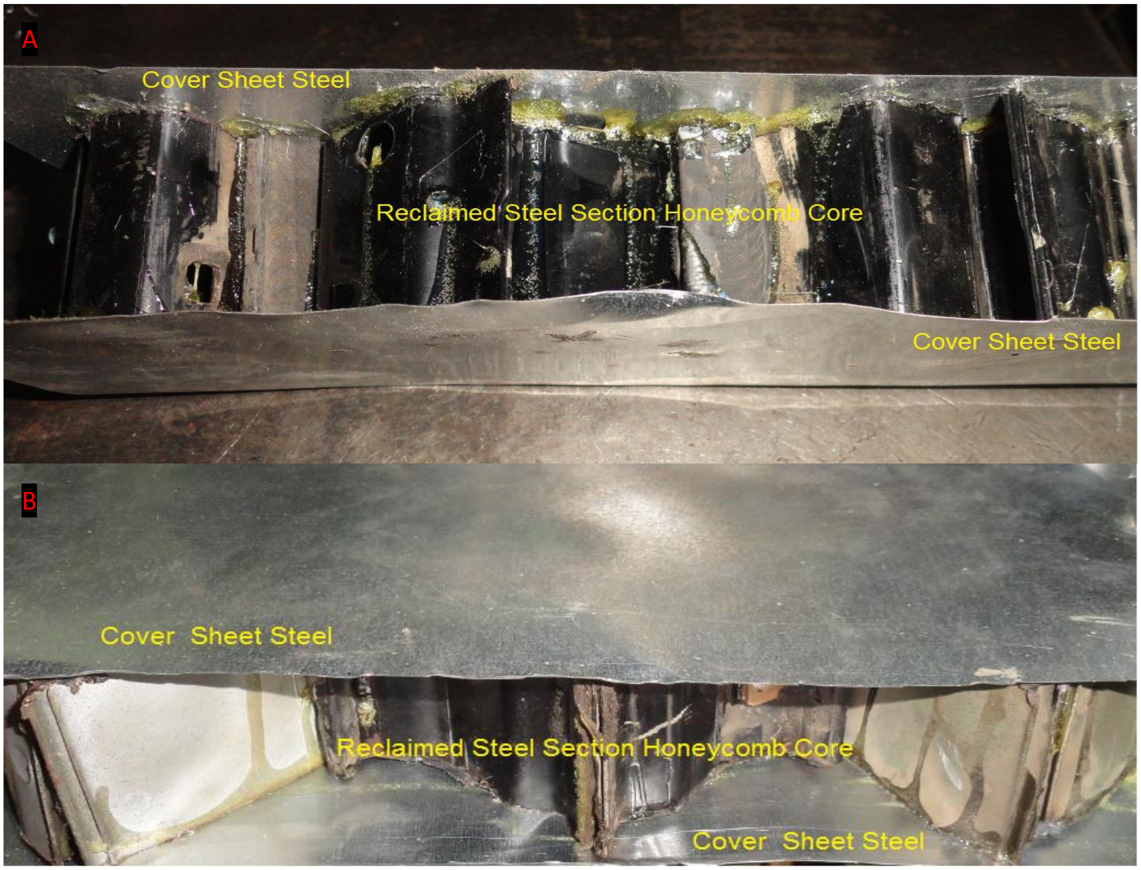

Fig. 9. Reclaimed steel sections cores are alignment between covers of Galvanized sheet steel of (0.2 mm) thickness

The produced cores are alignment on base of galvanised steel sheet of (0.2mm) thickness and cover at the top, Fig. 9. Painted and cladding steels can be used also and lower thicknesses are also possible to be used. The function of cover and base sheets is decoration, although they can give some strength support for cores. Universal purpose adhesive is used and fixed weight of (20kg) is applied for one day and samples are left for several days before test until the adhesive dries completely.

3. RECLAMATED STEEL HONEYCOMB TESTING

Three points bending and buckling tests, Fig. 10, are performed by using universal tensile testing machine ,(DNS100), Fig. 11, and recorded data of mechanical properties is obtained. Prepared samples are measured to conduct mechanical properties testing, where (270x113x50mm) are dimensions of Front Pillar honeycomb specimens, (286x102x50mm) are dimensions of Center Pillar honeycomb specimens, and (288x135x50mm) are dimensions of Roof Rail honeycomb specimens. Thus specimens flow the ASTM C393 standard which states that cross section of honeycomb should be rectangular [12]. Some data of bending and buckling tests are used, specially bending and buckling yield stresses to conduct feasibility of reclamation study. Also stiffness is used to find out values of displacement of both tests. Tested specimens are disassembly to help explanation of failure behavior study. Bending deformation predominates in both tests of bending and buckling. Tearing of holes and bending of screws at the middles cells are simultaneous failure modes to be taken place.

4. RESULTS AND DISCUSSION

Behaviors of test samples under bending load are illustrated in Figs. 12 to 14. Load-Position curves come with non-linear concave elastic locus of load varying with position for Center

Pillar honeycomb, while non-linear convex elastic locus predominates for both of Front Pillar and Roof Rail honeycomb test samples. This may be due to similarity in mass distribution style and continuity of their structures inside the hulk of the vehicle.

Fig. 10. Three points bending and buckling tests

Fig. 11. Universal Testing Machine DNS100

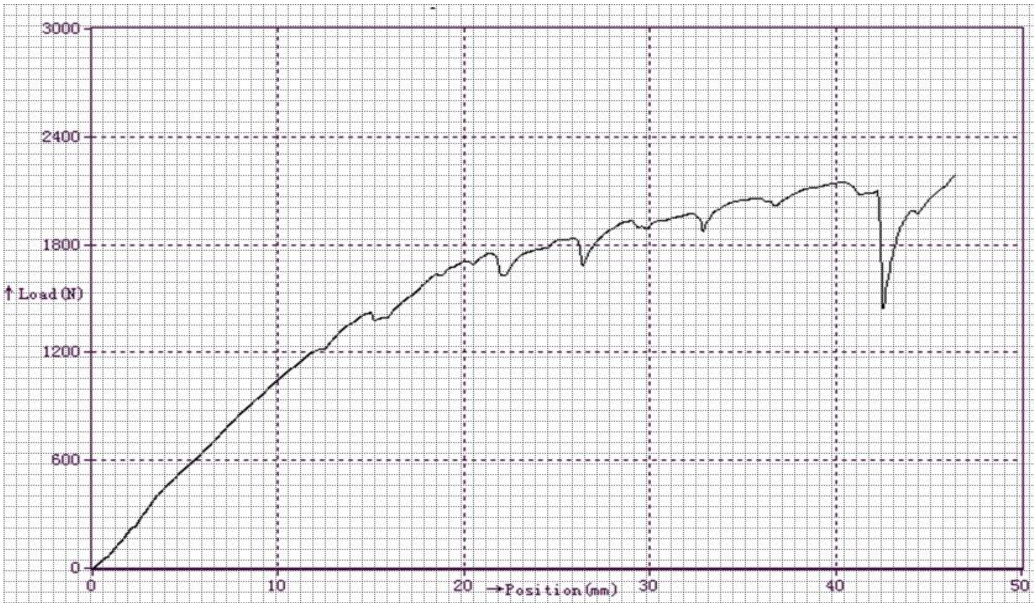

Fig. 12. Bending load-position curve for Front Pillar honeycomb

Fig. 13. Bending load-position curve for Center Pillar honeycomb

Table 1. Mechanical properties of bending test

Section no.	Section name	Section Recognition Ratio(H/D)	Cell Wall Thickness (mm)	Bending Yield Stress (N/mm^2)(σ_{BEY})	Bending Moment (N.mm)	Section Modulus (Z_{xx})(mm^3)	Specific Weight (Kg/m^2)
1	Center Pillar	0.49	2	1.926	168362.194	87393.6	9
2	Front Pillar	0.44	2	1.783	191213.055	107259.6	10
3	Roof Rail	0.37	1	0.410	62836.272	153090	5.5

Fig. 14. Bending load-position curve for Roof Rail honeycomb

Table 1 is a record of data of mechanical properties of bending test, yield stress of bending test is used to find out an indication about the strength of reclamation of steel honeycomb. Height to biggest dimension at section plane ratio (H/D) is also called recognition ratio which is calculated for the three sections as following:

Recognition ratio (H/D) = Height to biggest dimension at section plane ratio (H/D) =H/D
=50/102=0.49(for Center Pillar)
=50/113=0.44(for Front Pillar)
=50/135=0.37(for roof Rail)

Where:

H: height of unit cell (mm)
D: Biggest dimension at section plane of unit cell (mm)

Behavior of samples undergoes non-linear elastic limit at the beginning segment of load-position curve but for comparison purposes, material is supposed to obey Hook's law. Bending moment and bending yield stress are calculated and recorded in Table 1 at load of (1177.358N) and displacement of (26mm) for Center Pillar where the first yield point can be observed on load-position curve, at load of (1416.393N) and displacement of (22.5mm) for Front Pillar and at load of (436.363 N) and displacement of (18.5mm) for Roof Rail. Honeycomb is proposed as a beam of rectangular cross section with tendency to bend in x-x axis and moment is multiplication of upper yield load by half the length of the beam so calculations are based on the following equation:

$$Z=H.D^2/6 \text{ ----------} \quad (1)\ [13]$$

Where:

Z= Section modulus (mm^3)
H= height of unit cell (mm)
D= Biggest dimension at cell plane (mm)

So that bending yield stress can be calculated as the following:

$$\sigma_{BY} = M/Z \text{----------} \quad (2)\ [13]$$

Where:

M: bending moment (N.mm)

Because of two sections are of (2mm) cell wall thickness, while the third section is only of (1mm) thickness, so thickness and recognition ratio (H/D) are dependent variables of bending yield stress. Bending yield stress decreases slightly with decreasing of recognition ratio (H/D) when the thickness is constant. This behavior can be concluded through comparing between Center Pillar and Front Pillar due to high regularity in shape of Center Pillar where more mass is distributed inside the cell center to increase packing and density of the cell, as shown in Fig. 16, and even there are rounded contact area between cells but the screw assembly mechanism can apply enough axial force to provide stability where moderate active interaction between cells. This behavior is reflected as increasing in value of bending yield stress of Center Pillar honeycomb comparing with Front Pillar one. Lower stable structure can be gotten through screw assembly mechanism for cells of Front Pillar where shapes of cells are a little irregular where some mass is distributed far from the center of the cell to surrounding area to form lower density cell which is reflected as decreasing in bending yield for this honeycomb.

Decreasing in both of recognition ratio (H/D) and thickness of Roof Rail cores lead to decrease bending yield stress to be the lowest, Table 1. Such behavior can point out that decreasing of wall cells thickness, as in case of Roof Rail, can bring more weakness to the core which is already weak due to low density of enlarged section area with more irregularity. In insight of the bending load behavior, much more uniformity of mass distribution in section plane can increase bending strength where moment of inertia will enhance due to gathering of active interaction between cells and screw assembly mechanism. This can lead to conclude that rigidity of the core depends on mass distribution of the cells which identifies the increasing of strength with increasing of height to biggest dimension at section plane ratio and thickness of honeycomb core and fastening method with screw increases flexibility of cores. This behavior can be seen through illustration of Fig. 15. Interaction between cells statutes of cores can have an effect also on such behavior where fuzzy logic comparison are used to highlight it.

Behaviors of samples under buckling load are shown in Figs. 17 to 19 where Load-Position curves are shown. All curves show much more uniform behavior comparing with bending loading behaviors. Linear uniform loading behavior at the beginning of the curve, this segment of the curve is used to compare testing samples where elastic buckling loads (F_{BCE}) belong. This part of curve is followed by non-linear loading locus to be followed by linear loading path again until the peak of the load is reached. For buckling loading behavior, Center Pillar honeycomb is stiffer comparing with other cores ,where Roof Rail one is of the lowest stiffness, which based on values of bending Young's Modulus in Table 2 which is a record of mechanical properties data of buckling tests. More informative data can be used for design along the load-position curve, as example for proportional elastic load range, bending load and bending Young's Modulus are calculated and recorded in Table 2, where the proportional elastic limit ends at load of (266.667N) and displacement of (5.769mm) for Center Pillar, at load of (300N) and displacement of (4.063mm) for Front Pillar and at load of (66.667N) and displacement of (1.923mm) for Roof Rail. Honeycomb is proposed as a beam of rectangular cross section with tendency to bend in y-y axis and the beam is of two fixed ends so that half the length of the beam is used for calculations based on the following equation.

$$W_{cr}=\pi^2 E\, I \,/\, L^2 \text{ --------------- } \quad (3)\ [13]$$

Where:

W_{cr}: Crippling load (N)
E: Young's Modulus (Mpa)
I: moment of inertia (mm^4)
L: length of honeycomb test sample beam (mm)

There is a decreasing in buckling elastic load (F_{BCE}) with decreasing in section recognition ratio (H/D) as show in Fig. 20. Roof Rail core, followed by Front Pillar core, includes more irregular distribution of mass around the perpendicular axis on the section plane so lower moment is required as an indicator for buckling yield stress decreasing. Center Pillar is of high value of buckling yield stress due to uniformity of mass distribution through the section plane. Stiffness is also a proportional function to re-distribution of mass through the whole honeycomb sandwich panel according to Young's Modulus in Table 2. Variation of buckling elastic displacement with height to biggest distance at section plane ratio (H/D) of honeycomb cell is illustrated in Fig. 21.

5. ECO-COMPARISON BASED ASSESSMENT

Eco-comparison energy ratio based mitigation can be used to study feasibility of reclaimed steel to reduce energy consumption by comparing with recycled metals as shown in Fig. 22. It is clearer to introduce the following terms:-

RMS :Reclaimed Steel
RCS :Recycled Steel
RCSS :Recycled Stainless Steel
RCA :Recycled Aluminium
RMS :Reclaimed Steel
VS :Virgin Steel

VSS :Virgin Stainless Steel
VA: Virgin Aluminium

Eco-comparison energy ratio can be calculated based on mean values as the following :-

Mitigation $ratio_{1(energy)}$= ((RCS-RMS)/RCS)=(7.3-0.33)/7.3 x 100%=95.5%

Mitigation ratio $_{2(energy)}$= ((RCSS-RMS)/ RCSS)=(12-0.33)/12 x 100%=97.25%

Mitigation ratio $_{3(energy)}$= ((RCA-RMS)/RCA)=(26-0.33)/26 x 100%=98.73%

It is easily seen that high percentages of energy can be maintain by application of reclamation process where mitigation ratio1 shows the reduction in energy to be (95.5%) when the comparison is done between reclaimed steel and recycled steel. Comparison with stainless steel and Aluminium shows that reclaimed steel can reduce (97.25%) and (97.25%) respectively.

Eco-comparison Co_2 emission ratio based mitigation to study feasibility of reclaimed steel to reduce Co_2 emission generation by comparing with (RCA) only because generated Co_2 emission for both of (RCS) and (RCSS) are within the same or a little lower than the level of the obtained Co_2 emission by application of reclamation as explained by Fig. 23. The ratio can be calculated based on mean values as the following :-

Mitigation ratio $_{(Co2\ emission)}$= ((RCA-RMS)/RCA)=(2.1-0.94)/2.1 x 100%=55.24%

It is easily can be seen that high percentages of Co_2 emission can be maintain by application of reclimation process where mitigation ratio shows the reduction in Co_2 emission to be (55.24%) when the comprison is done between reclaimed steel and aluminium.

Since percentage reduction of energy are not sensitive to very high reductions, as in this case, eco-comparison energy ratio based mitigation is replaced with area under the curve of mean values of energy range for each type of metals (RMS),(VS)(VSS) and (VA) to study feasibility of reclaimed steel to reduce energy consumption by comparing with energy consumption for virgin metals manufacturing. This ratio can be calculated based on integration of area under each curve of mean values as in Fig. 24 where area under curve of Reclaimed Steel(RMS) is (0.942MJ/Kg), of Virgin Steel (VS) is (162 MJ/Kg), of Virgin Stainless Steel (VSS) is (386.16 unit area) and of Virgin Aluminium (VA) is (893.98 MJ/Kg). It is easily to be seen that high percentages of energy can be maintain by application of reclamation process where mitigation area can variety from (161.058 MJ/Kg) comparing with virgin steel and (381.218 MJ/Kg) comparing with stainless steel to (893.038 MJ/Kg) comparing with virgin aluminium.

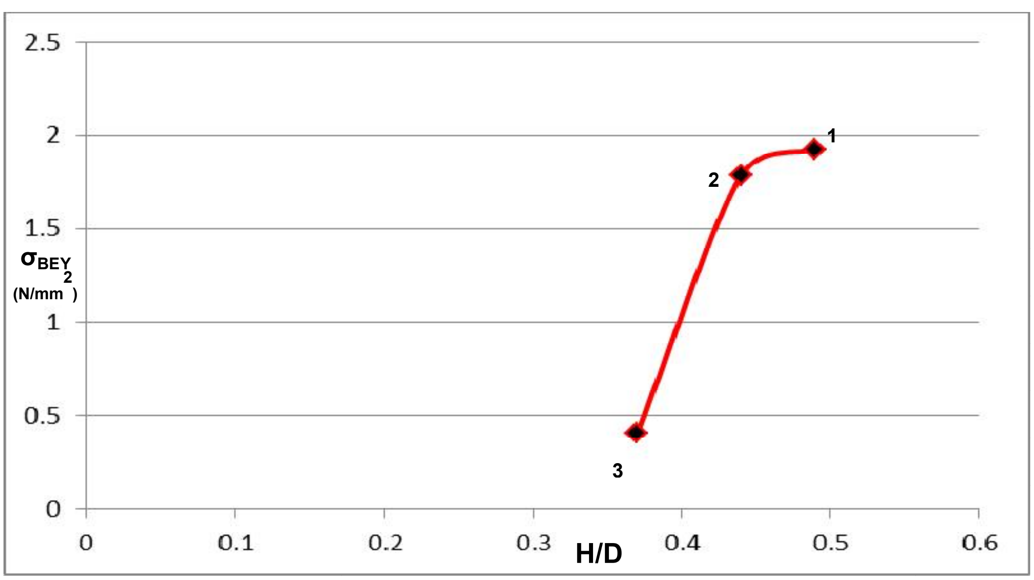

Fig. 15. Variation of bending yield stress (σ_{BEY}) with height to biggest dimension at section plane ratio (H/D) of honeycomb cell

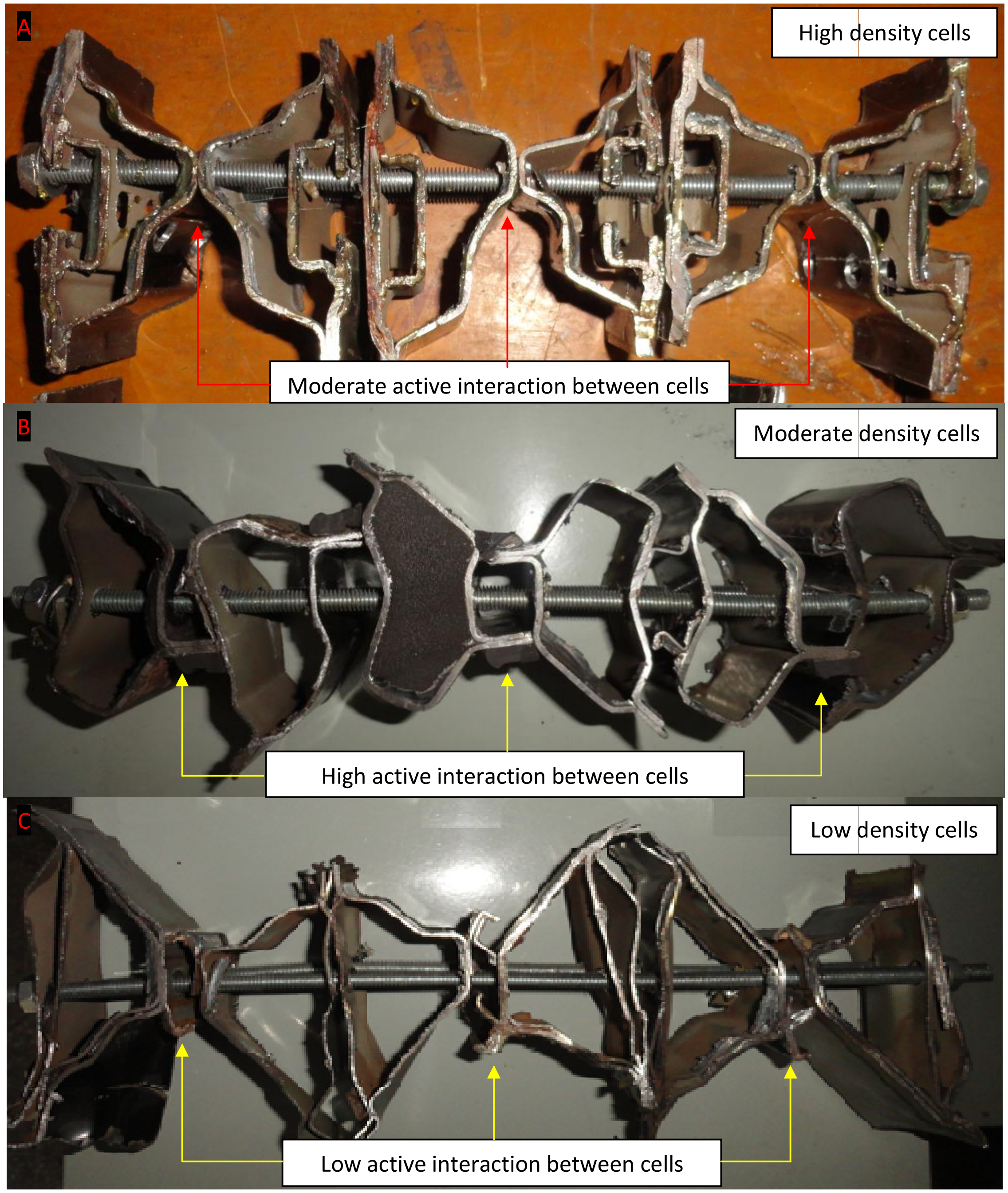

Fig. 16. Illustration of fuzzy logic comparison to explain interaction between cells statutes of cores of Center Pillar (A), Front Pillar (B) and Roof Rail (C)

Table 2. Mechanical properties of buckling test

Section no.	Section Name	Section Recognition Ratio(H/D)	Cell Wall Thickness (mm)	Buckling Elastic load (N)(F_{BCE})	Displacement (mm)	Young's Modulus (Mpa)	Moment of Inertia (I_{yy})(mm^4)
1	Center Pillar	0.49	2	266.667	5.769	0.508	1088204.540
2	Front Pillar	0.44	2	300.00	4.063	0.460	1205559.936
3	Roof Rail	0.37	1	66.667	1.923	0.097	1440270.720

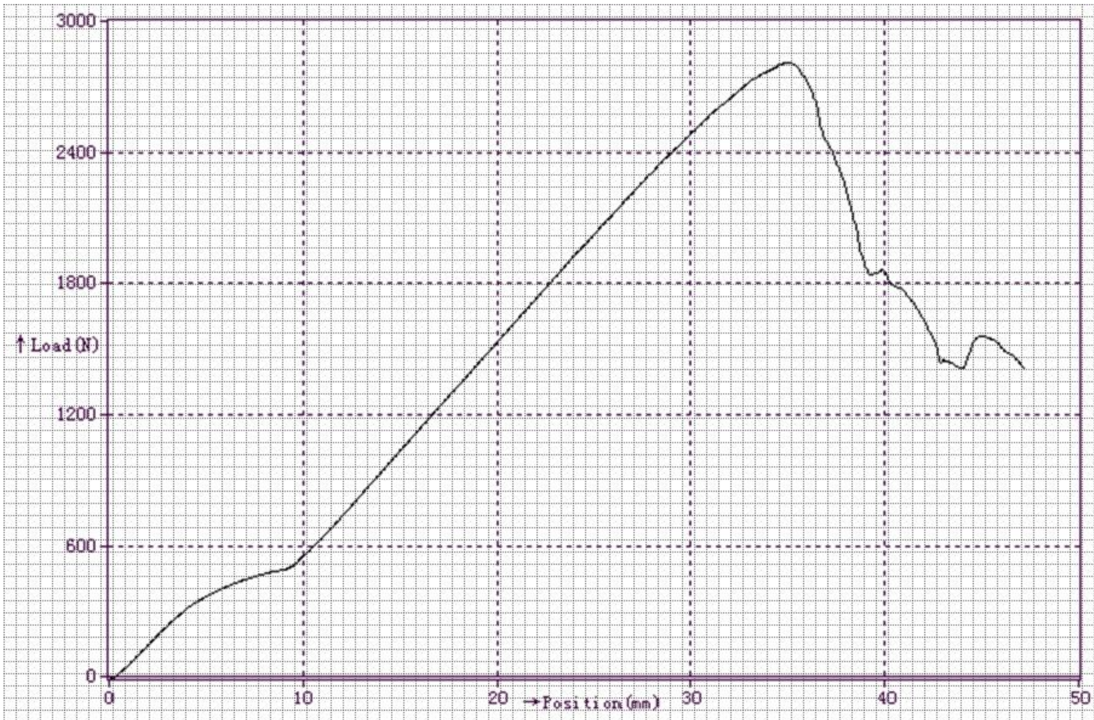

Fig. 17. Buckling load-position curve of Front Pillar honeycomb

Fig. 18. Buckling load-position curve of Center Pillar honeycomb

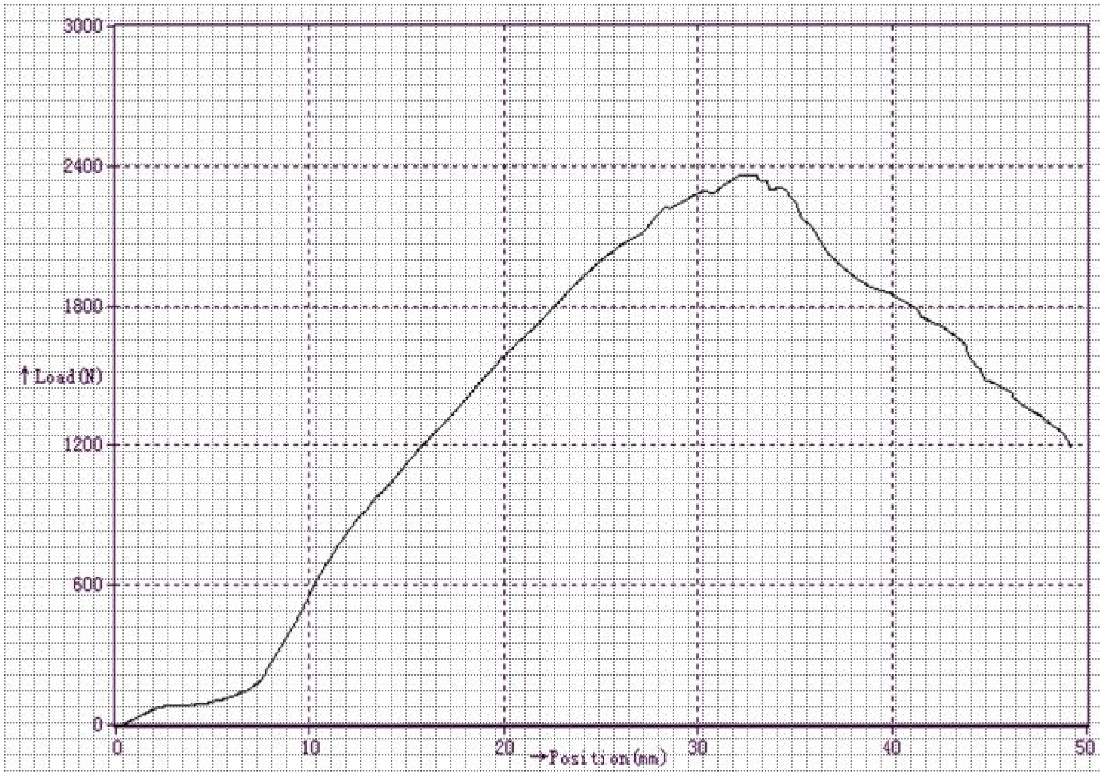

Fig. 19. Buckling load-position curve of Roof Rail honeycomb

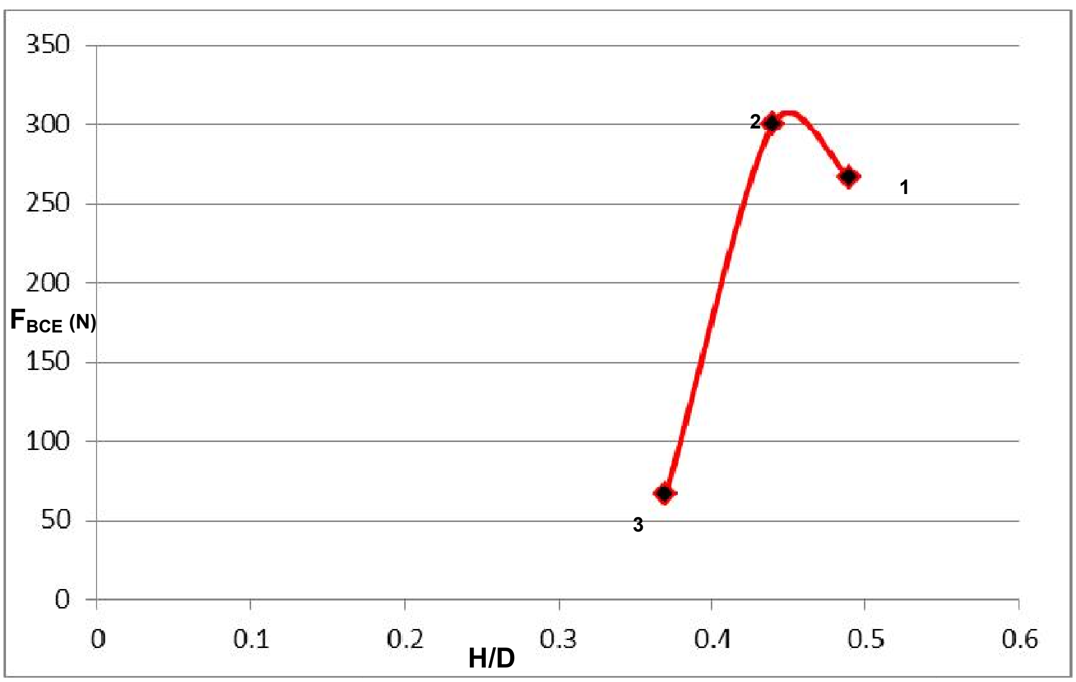

Fig. 20. Variation of buckling elastic load (F_{BCE}) with height to biggest distance at section plane ratio (H/D) of honeycomb cell

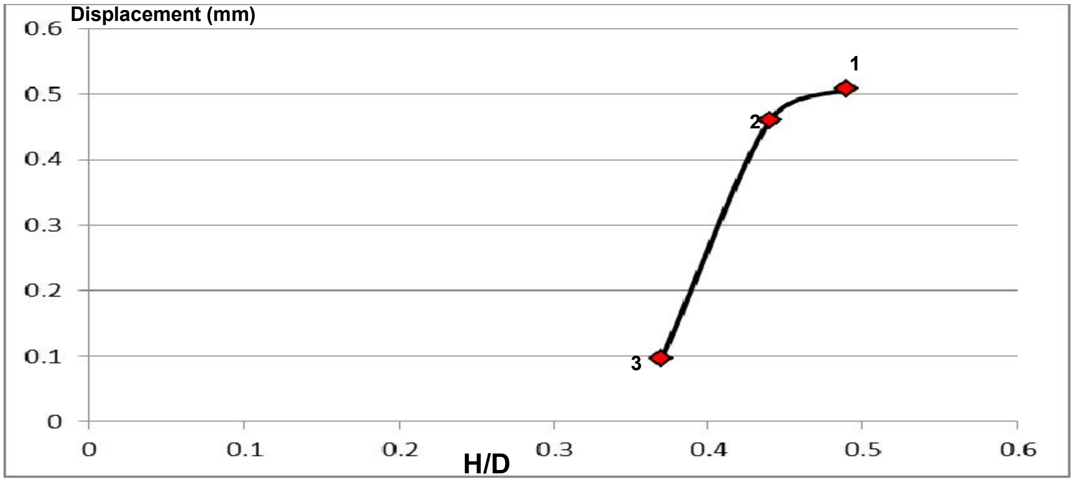

Fig. 21. Variation of buckling elastic displacement with height to biggest distance at section plane ratio (H/D) of honeycomb cell

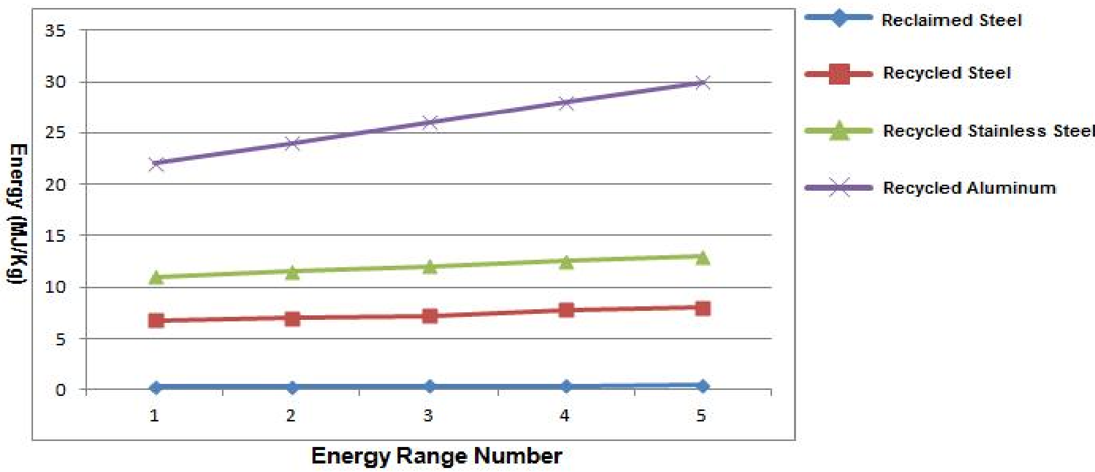

Fig. 22. Energies (MJ/Kg) of reclaimed and recycled metals [2,14]

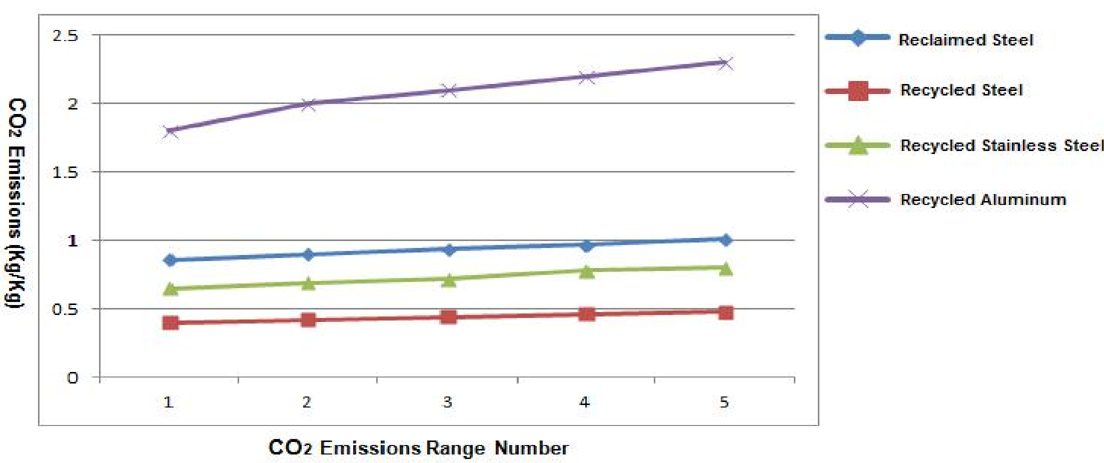

Fig. 23. CO_2 emissions (Kg/Kg) of reclaimed and recycled metals [2,14]

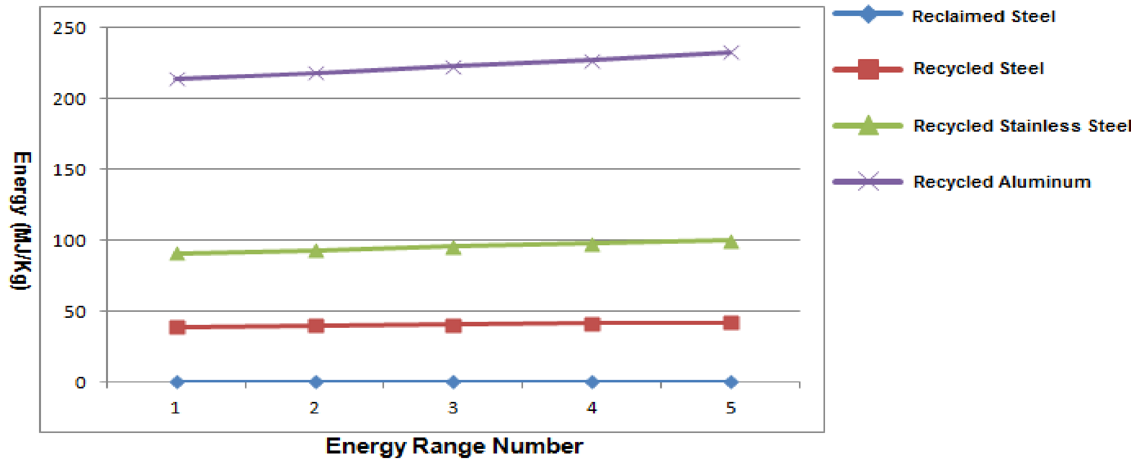

Fig. 24. Energies (MJ/Kg) of reclaimed and virgin metals [2,14]

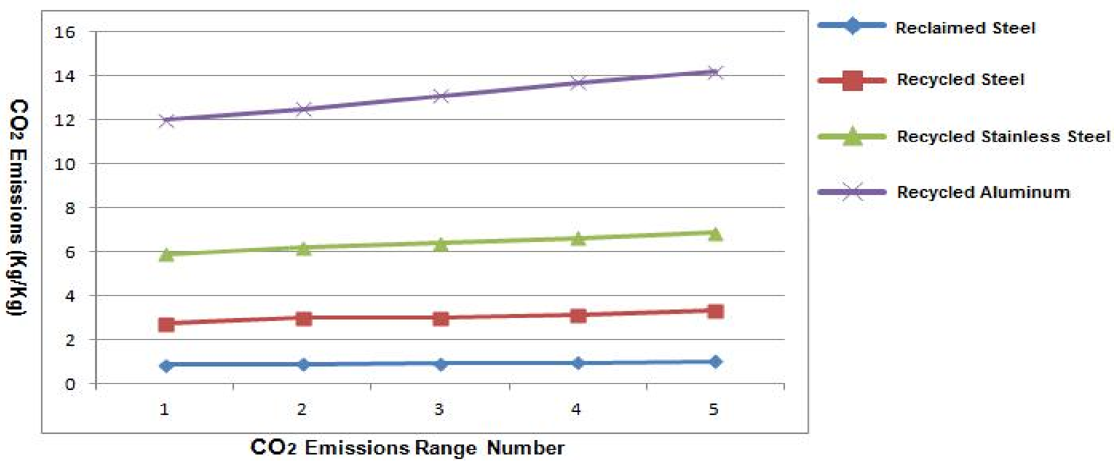

Fig. 25. CO_2 emissions (Kg/Kg) of reclaimed and virgin metals [2,14]

Eco-comparison Co_2 emission ratio based mitigation is conducted to study feasibility of reclaimed steel to reduce generated Co_2 emission by comparing with (VCS),(VCSS) and (VCA). It is easily can be seen that high percentages of Co_2 emission can be maintain by application of reclamation process where mitigation ratio shows the reduction in Co_2 emission to be(68.56%) ,(85.81%) and (92.78%) when the comparison is done among reclaimed steel and virgin steel, virgin stainless steel and virgin aluminium respectively, as shown in Fig. 25. The ratio can be calculated based on mean values as the following:-

Mitigation ratio$_1$($Co_{2\ emission}$)= ((VCS-RMS)/VCS) =(2.99-0.94)/2.99 x 100%=68.56%

Mitigation ratio$_2$ ($Co_{2\ emission}$)= ((VCA-RMS)/ VCA)=(6.4-0.94)/6.4 x 100%=85.81%

Mitigation ratio$_3$($Co_{2\ emission}$)= ((VCA-RMS)/VCA)= (13.08-0.94)/13.08 x 100%=92.78%

6. CONCLUSION

- Three sections of end-of-life vehicle frames are used to be reclaimed into steel honeycomb cores and used to make samples of sandwich panels for construction applications.
- Manual tools are used to disassembly hulk steel frames of end-of-life vehicle.
- Two thirds or more of end-life-life vehicles can be used as raw material for honeycomb sandwich panels producing.
- Steel frames are of high value-added to be reclaimed where mature technology are used to form steel by hot stamping and coating and painting films are of very

powerful protection comparing with new sheet steel.

- Uniform distribution of mass around the perpendicular axis on the section plane can help produce strong reclaimed honeycomb through using of light weight sections with better distribution of mass to be fulfilled for reclaimed honeycomb producing with good mechanical properties to play as eco-design feedback.
- Good buckling strength can introduce such reclaimed steel honeycombs to be used for partition walls and fair bending strength can fulfill them for roofs.
- High reduction of energy is obtained comparing with recycled steel, stainless steel and aluminium.
- Reduction of Co_2 emission is within the limits of recycled steel and stainless steel but good reduction of emission is obtained comparing with recycled aluminium.
- High reduction of energy is obtained comparing with virgin steel, stainless steel and aluminium.
- High reduction of Co_2 emission is obtained comparing with virgin steel, stainless steel and aluminium.
- Automation application is required to cope with manpower and time consuming of such reclamation process.
- Regularity and uniformity of mass distribution have high effect on mechanical properties of honeycomb panels.
- Screws assembly of cells for Roof Rail can produce cores of high shape stability value to let the bending yield stress to be the biggest which is followed by the Front Pillar section and the lowest value is for the Center Pillar.
- Reclamation can be used as powerful feedback tool for eco-design ideas.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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