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A REVIEW ON APPLICATION AND MECHANICAL PROPERTIES OF HOLLOW TUBULAR SECTION

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Abstract

This paper presents a comprehensive review of the literature on hollow tubular structures, with applications ranging from traditional engineering structures to from simple circular tubes to modern corrugated structures. As such it provides an important reference for researchers to have a broad epigrammatic cognizance of the mechanical behavior of these structures. Hollow structures have long been seen as a simple and effective means of light weight structures with high stability under buckling load and energy absorption capability. This has been used in numerous industrial and academic applications. In recent years there have been numerous innovative developments to hollow tubular structures, involving more bewildering and inventive hollow structures which are better than solid structures as well as aesthetically more appealing. The use of corrugation and advanced composite materials are giving an added advantage by the virtue of which researchers can easily alter these structures and can make it beneficial or transform it according to their desired application.

Key words: hollow tubular structure, corrugated structures, buckling load, energy absorption capability

1. Introduction

Many examples in nature shows the excellent properties of the tubular form regarding loading in all directions of compression, torsion and bending, see Figures. 1a and 1b These excellent properties are combined with an appealing architectural form. The closed form without sharp corners further decreases the area to be covered and increases the life cycle of corrosion safety.

The hollow sections are the most flexible and efficient type for mechanical and construction applications. Without hollow parts, many of the strongest and most powerful structures in the world today would not have been possible. The tubular shape is strong and inherently efficient. It gives buildings a higher strength to weight ratio than those using equivalent materials made of steel, concrete or timber. This strength to weight ratio decreases material use in building and allows for larger spans. This results in light weight, airy structures that make our societies and environments aesthetically pleasing. Hollow parts have broad and varied use. For instance, hollow parts have been used in iconic structures such as the London Eye, Emirates Stadium and the world record-breaking JCB Dieselmax space frame structure. They are also suitable for daily uses such as truck trailers, fences and handrails.

Another feature that is particularly beneficial for circular hollow parts when exposed to wind or water forces is the lower drag coefficients. The internal gap may be used in different ways , e.g. to increase the resistance of the bearings by filling with concrete or to provide protection against fire. Moreover, often the heating or ventilation system makes use of the columns of the hollow portion. On the basis of the research programs, CIDECT (Comité International pour le Développement etl'Étude de la Construction Tubulaire) has published design guides [1 to 8] for practical use by designers.

1.1 History and Developments

In 1951, Jamm [9] provided the first preliminary design recommendations about truss relations between circular hollow parts. A variety of inquiries followed this analysis in Japan [10,11], the USA [12,13,14], and Europe [15 to 23]. Research on linkages between rectangular hollow sections began in Europe in the 1960s, followed by several other experimental and theoretical investigations. CIDECT funded a number of all those. In addition to these studies on static behaviour, a great deal of research has been conducted over the past 25 years on fatigue behaviour and other factors such as concrete filling of hollow parts, fire resistance, corrosion resistance and wind loading behaviour.

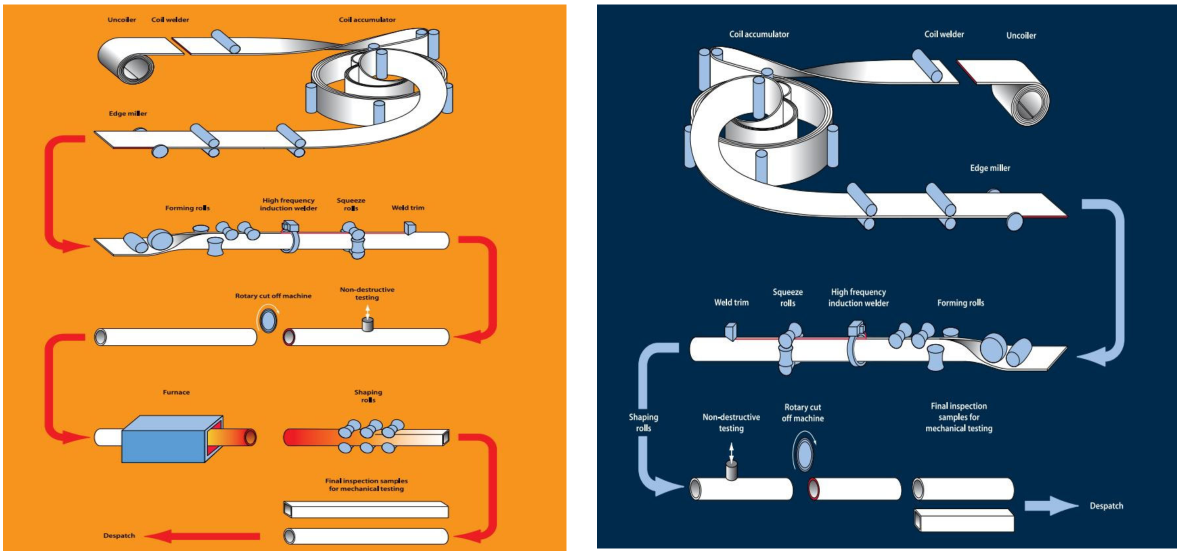
1.3 Manufacturing of Hollow Sections

Hot finished and cold formed hollow parts are very different methods of manufacture. Hot finished hollow as shown in Fig.1csections is formed at standardizing temperature (approx. 900° C) and developed in compliance with EN10210-1 standards. Cold formed hollow parts are formed at ambient temperature as shown in Fig.1d and are developed in compliance with the EN10219-1 standards. That results in a number of major differences. The key difference is that hot finished hollow parts move through a furnace and have a much closer corner profile during the formation process as a result of the metal flow (EN10210-2). On the other side, cold formed show a high degree of cold working in the corner regions during the process of formation. This indicates that if produced with close radius corners they could be sensitive to corner cracking.

The term corrugated, describes a series of parallel ridges and furrows [24]. Corrugated structures are those which has a surface with the shape of corrugation either made by folding, moulding, or any other manufacturing methods. Typically, corrugated structures can be categorized as: a corrugated pipe, a corrugated sheet and a corrugated panel. The most common feature of all corrugated structures is their extremely anisotropic behaviour; high transverse stiffness to the direction of corrugation, as opposed to compliance along the direction of corrugation [25]. Due to this paramount trait these structures have been vaguely accepted in academic research and industrial applications. Even now a days many studies undertakes the post-fire stub column behaviour of cold-formed steel elliptical hollow sections (CFS-EHS) [41].

(a) Bamboo

(b) Reeds in Winds



(c) Hot Working (d) Cold Working

Fig 1 Examples and manufacturing of tubular sections

2. Applications of Corrugated Structures

Due to their remarkable features such as: high strength to weight ratio and high capacity of energy absorption these hollow structures have wide application in engineering. Typically hollow parts are used to express a lightness due to the elegance of their shape, or in other cases their geometrical characteristics dictate their use. Its application are classified into the subsequent class in which more value is given to the special characteristics of these structures.

2.1Automotive Industry

Leakage of fluids and liquids, heavy vibrations as well as great heat generation- these are only a few of the many pressures that cables used in the automotive sector have to cope with. Without corresponding protection, substantial cable damage may be the result - complete systems are the right solution to this problem in vehicle manufacturing. Corrugated tubes and protective hoses with varying properties, from heat resistance to abrasion safety and impact resistance to noise reduction, shield important cables from all unfavorable external factors.

2.2 Civil Structures

- **Buildings, Halls, Etc.**

Hollow pieces are primarily used in buildings and halls for columns and lattice girders, or roof space frames. They are also used in modern architecture for other structural or decorative purposes, for example facades.

- **Towers and Masts**

With wind loading, corrosion safety and architectural appearance in mind, there is no question that hollow parts are preferable. Nowadays, architectural beauty is becoming more important and the safety and maintenance is more costly due to the environmental constraints. These factors fuel designs made from hollow parts.

- **Bridges**

The Firth of Forth Bridge is an outstanding example of using the shape of a hollow section for structural bridge applications. Circular hollow sections are also commonly used for plate girders flanges.

2.2 Mechanical Engineering Structures

- **Corrugated hoses**

The 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 [26]. Because of these characteristics they are mostly used in hydraulic circuits, electrical cable safety and light conductors, or exhaust gas installations. Corrugated hoses also show corrosion resistance and tightness of pressure in the most severe conditions, such as hostile seawater, high temperatures encountered in space and conveying extremely hot or cold liquids. In mechanical engineering hollow structures are extensively used in jibs, cranes and various other machinery.

3. General Mechanical Properties of Hollow Corrugated Tubes

3.1 Compression

For the weak axis of an open section, the gyration radius of a hollow section (in comparison to the member mass) is usually much greater than that. Buckling behaviour is affected by initial eccentricity, straightness and geometric tolerances, as well as residual stresses, steel non-homogeneity, and stress-strain relationship [34-36]. "European buckling curves" (Fig.3) were developed for different steel sections including hollow parts, based on an comprehensive investigation by the European Convention for Constructional Steelwork and CIDECT.

The overall hollow section buckling behaviour improves with increasing ratio of diameter or width to wall thickness. However, local buckling restricts the change. For avoiding local buckling, e.g. in Eurocode 3, d / t or b / t limits are given, see table 1 where ‘d’ is the external diameter, ‘t’ is the thickness, ‘b’ is the width of the tube and ‘a’ is the side of the square hollow tube.

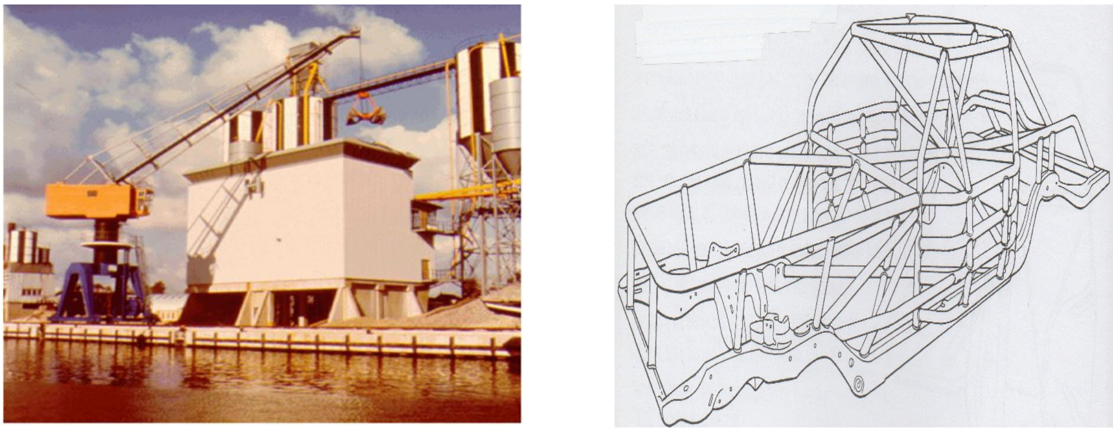
3.2 Buckling of corrugated tubes

A comprehensive analysis of improving the stability of tubes using deep shell theory have been provided by Semenyuk and Neskhodovskaya [27, 28]. The application of corrugation on a cylindrical shell can considerably raise the critical buckling load. The shell approach suggests that a modification to the curved surfaces of a true wing may be viable and maybe a further extension to involve the effects of surface pressure along the lines of Semenyuk et al. [29].


(a) Roof with lattice girders


(b) Roof with tubular sections

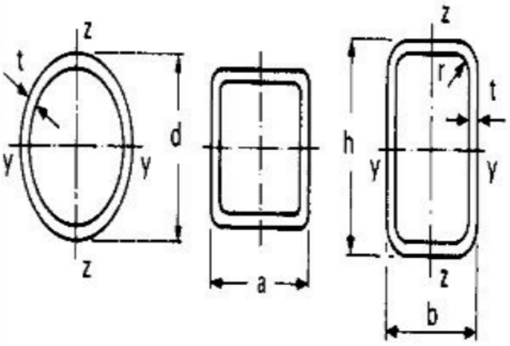
(c) Firth of Forth Bridge (d) Crane



(e) Jib (f) Space frame of automobile

Fig 2: Applications of tubular sections

Table 1. Euro code 3, d / t or b / t limits

Cross Section	Manufacturing Process	Buckling Curve
	Hot forming	a
	Cold forming (fyb used)	b
	Cold forming (fya used)	c

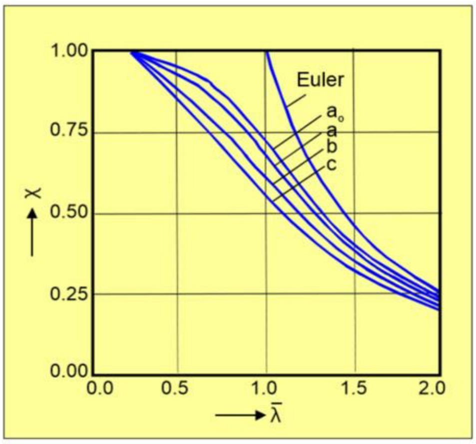


Fig 3: Buckling curves according to manufacturing process

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Table 2: d/t limits to prevent local buckling [40

	Class		**1**			**2**				**3**			
Cross section	Load Type	Considered element	275	355	460	235	275	355	460	235	275	355	460

RHS	Compression	Compression	41.6	36.6	32.2	45	41.6	36.6	32.2	45	41.6	36.6	32.2
RHS	Bending	Compression	33.3	29.3	25.7	41	37.9	33.4	29.3	45	41.5	36.6	32.2
RHS	Bending	Bending	1	1	1	1	1	1	1	1	1	1	1
CHS	Compression and/or Bending		42.7	33.1	25.5	70.0	59.8	46.3	35.8	90.0	76.9	59.6	46

- There is no difference between b/t and h/t limits for the classes 1, 2 and 3, when the whole cross section is only under compression.
- Class 3 limits appear when section is in compression

3.3 Vibration

Vibration is an important factor in engineering; low weight demand can also result in low damping structures that can cause destructively high amplitude vibrations if the modes are excited at their natural frequencies. Structural vibration is also, in general, an important concern for topics like noise and passenger comfort in vehicles [37]. Deep shell theory and the Hamilton principle were used by Semenyuk et al. [30] to provide a detailed analysis of the vibrations of a corrugated cylindrical shell, observing both local and global effects at the same time. Homogenized approaches have been shown to capture the first vibration mode only over a small 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 vibrations occur in-plane. Gulgazaryan and Gulgazaryan [31] identified the geometric conditions that could lead to the existence of Rayleigh waves along the free edge of a corrugated cylindrical shell in another analytical survey based on deep shell theory.

3.4 Internal Pressure

The circular hollow section is ideally suited to withstand an internal pressure of ‘p’. The capacity of the design per unit length, thickness ‘t’ and diameter ‘d’ is given by:

$$p = f_y \frac{2t}{d-2t} \frac{1}{\gamma_M}$$

Depending on the product's threat, the impact of failure on the environment and the capacity to inspect can be substantially greater than in other situations for transport pipelines. The design capacities for internal-pressure RHS parts are much more complicated; reference may be made to [32].

4. Uses of Internal void

The internal gap in hollow parts may be used in different ways , e.g. to increase the compressive resistance by filling with concrete, or to provide protection against fire. Moreover, the heating or ventilation system is often installed in hollow columns of the segment.

4.1 Concrete Filling

Concrete filling of hollow parts not only leads to improved load resistance of the bearings, but it also improves the fire resistance duration. The extensive test projects carried out by CIDECT and ECSC (European Coal and Steel Community) have shown that reinforced concrete-filled hollow section columns without any external fire protection like plaster, vermiculite panels or intumescent paint, can also have a fire life of 2 hours depending on the steel and concrete cross-section ratio, reinforcement percentage of the concrete and the applied load [33].

4.2 Fire Protection By Water Circulation

The use of water-filled hollow section columns is one of the latest methods for fire protection of buildings. The columns are interconnected to a tank for water storage. The water circulates through convection under fire conditions, thus maintaining the steel temperature below the critical value of 450 ° C. This method has benefits economically. If the flow of water is sufficient, the resulting time for fire resistance is virtual unlimited

4.3 Heating and Ventilation

Often the inner voids of hollow parts are used for the circulation of air and water to heat and ventilate buildings. This system provides floor area maximization by removing heat exchangers, offering uniform warmth and combined fire protection [37-38].

5. Conclusion

Hollow structures have noticeable impacts on the engineering applications due to their superior structural characteristics such as high strength to weight ratio, mainly arising from their geometric properties. In this paper a detailed review of the literature on tubular structures was presented. It described their specific characteristics and their categorized applications. Extending their applications, innovation and developments of these structures were discussed in terms of introducing further geometric parameters. Further these simple tubular structures can be replaced by the corrugation of different pattern which increases the overall mechanical properties of these structures due to its extreme anisotropic behaviour and high stiffness to weight ratio.

References

1. Wardenier, J., Kurobane, Y., Packer, J.A., Dutta, D. and Yeomans, N.: Design guide for circular hollow section (CHS) joints under predominantly static loading (1). CIDECT (Ed.) and Verlag TÜV Rheinland, Cologne, Germany, 1991. ISBN3-88585-975-0.
2. Rondal, J., Würker, K.G., Wardenier, J., Dutta, D. and Yeomans, N.: Structural stability of hollow sections (2). CIDECT (Ed.) and Verlag TÜV Rheinland, Cologne, Germany, 1991. ISBN 3-8249-0075-0.
3. Packer, J.A., Wardenier, J., Kurobane Y., Dutta, D. and Yeomans, N.: Design guide for rectangular hollow section (RHS) joints under predominantly static loading (3). CIDECT (Ed.) and Verlag TÜV Rheinland, Cologne, Germany, 1992. ISBN 3-8249-0089-0.
4. Twilt, L., Hass, R., Klingsch, W., Edwards, M. and Dutta, D.: Design guide for structural hollow section columns exposed to fire (4). CIDECT (Ed.) and Verlag TÜV Rheinland, Cologne, Germany, 1994. ISBN 3-8249-0171-4.
5. Bergmann, R., Dutta, D., Matsui, C. and Meinsma, C.: Design guide for concrete-filled hollow section columns (5). CIDECT (Ed.) and Verlag TÜV Rheinland, Cologne, Germany, 1995. ISBN 3-8249-0298-2.
6. Wardenier, J., Dutta, D., Yeomans, N., Packer, J.A. and Bucak, Ö.: Design guide for structural hollow sections in mechanical applications (6). CIDECT (Ed.) and Verlag TÜV Rheinland, Cologne, Germany, 1995. ISBN 3-8249-0302-4.
7. Dutta, D., Wardenier, J., Yeomans, N., Sakae, K., Bucak, Ö. and Packer, J.A.: Design Guide for Fabrication, Assembly and Erection of Hollow Section Structures (7). CIDECT (Ed.) and TÜV Verlag, Cologne, Germany, 1998. ISBN 3-8249-0443-8.
8. Zhao, X-L., Herion, S., Packer, J A., Puthli, R.S., Sedlacek, G., Wardenier, J., Weynand, K., Wingerde, A.M. van. andYeomans, N.F.: Design Guide for Circular and Rectangular Hollow Section Welded Joints under Fatigue Loading (8). CIDECT (Ed.) and TÜV Verlag, Cologne, Germany, 2000. ISBN 3-8249-0565-5.
9. Jamm, W.: Form strength of welded tubular connections and tubular structures under static loading. (Translation from German). Schweissen und Schneiden, Vol. 3, Germany, 1951.
11. Jim Noll, Steve Tysl, and Matt Westrich, (2009),The Use of Corrugated Metal Pipe and Structural Plate for Aggregate Tunnel and Conveyor Enclosure Applications, Professional Development Advertising Section , CONTECH Construction Products Inc.
10. Natarajan, M. and Toprac, A.A.: Studies on tubular joints in Japan: Review of research reports. University of Texas Report, U.S.A., 1968.
11. Togo, T.: Experimental study on mechanical behaviour of tubular joints. PhD thesis, Osaka University, Japan, 1967 (in Japanese).
12. Natarajan, M. and Toprac, A.A.: Studies on tubular joints in USA: Review of research reports. University of Texas Report, U.S.A., 1969.
13. Bouwkamp, J.G.: Concept on tubular joints design. Proceedings of ASCE, Vol. 90, No. ST2, U.S.A., 1964.
14. Marshall, P.W. and Toprac, A.A.: Basis for tubular design. ASCE preprint 2008, April 1973, also Welding Journal, U.S.A., 1974.
15. Brodka, J.: Stahlrohrkonstruktionen. VerlagsgesellschaftRüdolf Müller, Köln-Braunsfeld, Germany, 1968.
16. Dutta, D., Würker, K.G.: HandbuchHohlprofile in Stahlkonstruktionen, Verlag TÜV Rheinland GmbH, Köln, Germany, 1988. ISBN 3-88585-528-3.
17. Dutta, D.: Hohlprofilkonstruktionen. Ernst &Sohn, Berlin, Germany, 1999. ISBN 3-433-01310-1.
18. Mang, F., Bucak, Ö.:Hohlprofilkonstruktionen, Stahlbau-Handbuch, Bd. I, Stahlbau-Verlag, Köln, Germany, 1983.
19. Puthli, R.S.: Hohlprofilkonstruktionenaus Stahl

nach DIN V ENV 1993 (EC3) und DIN 18 800 (11.90), Werner Verlag GmbH & Co. K.G., Düsseldorf, Germany, 1998. ISBN 3-8041-2975-7.

20. Rautaruukki: Design Handbook for Rautaruukki Structural Hollow Sections. Hämeenlinna, Finland, 1998. ISBN 952-5010-22-8.
21. Stahlrohr-Handbuch: 9. Aufl. Vulkan-Verlag, Essen, Germany, 1982.
22. Wardenier, J.: Hollow Section Joints, Delft University Press, Delft, The Netherlands, 1982. ISBN 90.6275.084.2.
23. Wanke, J.: Stahlrohrkonstruktionen. Springer Verlag, Vienna, Austria, 1966.
24. "Corrugate." Merriam-Webster.com. 2014. http://www.merriam-webster.com.
25. Yokozeki, T., Takeda, S. I., Ogasawara, T., & Ishikawa, T. (2006). Mechanical properties of corrugated composites for candidate materials of flexible wing structures. Composites Part A: applied science and manufacturing, 37(10), 1578-1586.
26. Hachemi, H., Kebir, H., Roelandt, J. M., &Wintrebert, E. (2011). A study of the braided corrugated hoses: Behavior and life estimation. Materials & Design,32(4), 1957-1966.
27. Semenyuk, N. P., &Neskhodovskaya, N. A. (2002). On design models in stability problems for corrugated cylindrical shells. International applied mechanics, 38(10), 1245-1252.
28. Semenyuk, N. P., &Neskhodovskaya, N. A. (2002). Timoshenko-type theory in the stability analysis of corrugated cylindrical shells. International applied mechanics, 38(6), 723-730.
29. Semenyuk, N. P., Zhukova, N. B., &Ostapchuk, V. V. (2007). Stability of corrugated composite noncircular cylindrical shells under external pressure.International Applied Mechanics, 43(12), 13801389.
30. Semenyuk, N. P., Babich, I. Y., and Zhukova, N. (2005). Natural vibrations of corrugated cylindrical shells. International Applied Mechanics, 41(5):512–519.
31. Gulgazaryan, G. and Gulgazaryan, L. (2006). Vibrations of a corrugated orthotropic cylindrical shell with free edges. International Applied Mechanics, 42(12):1398–1413.
32. Deutscher Dampfkesselausschuß: GlatteVierkantrohre und TeilkammernunterinneremÜberdruck, TechnischeRegelnfürDampfkessel (TRD 320), Vereinigung der TechnischenÜberwachungsvereinee.V., Essen, Germany, 1975.
33. Twilt, L., Hass, R., Klingsch, W., Edwards, M. and Dutta, D.: Design guide for structural hollow section columns exposed to fire (4). CIDECT (Ed.) and Verlag TÜV Rheinland, Cologne, Germany, 1994. ISBN 3-8249-0171-4.
34. Bourada, M., Kaci, A., Houari, M.S.A. and Tounsi, A. (2015), “A new simple shear and normal deformations theory for functionally graded beams”, Steel Compos. Str#uct., 18(2), 409-423.
35. Hamidi, A., Houari, M.S.A., Mahmoud, S.R. and Tounsi, A. (2015), “A sinusoidal plate theory with 5-unknowns and stretching effect for thermomechanical bending of functionally graded sandwich plates”, Steel Compos. Struct., 18(1), 235-253.
36.AitYahia, S., AitAtmane, H., Houari, M.S.A. and Tounsi, A. (2015), “Wave propagation in functionally graded plates with porosities using various higher-order shear deformation plate theories”, Struct. Eng. Mech., 53(6), 1143-1165.
37.Attia, A., Tounsi, A., AddaBedia, E.A. and Mahmoud, S.R. (2015), “Free vibration analysis of functionally graded plates with temperature-dependent properties using various four variable refined plate theories”, Steel Compos. Struct., 18(1), 187-212.
38. Bouchafa, A., Bouiadjra, M. B., Houari, M. S. A., & Tounsi, A. (2015). Thermal stresses and deflections of functionally graded sandwich plates using a new refined hyperbolic shear deformation theory. Steel Compos. Struct, 18(6), 1493-1515.
39.Bouderba, B., Houari, M.S.A. and Tounsi, A. 2013) “Thermomechanical bending response of FGM thick plates resting on Winkler–Pasternak elastic foundations”, Steel Compos. Struct., 14(1), 85-104.
40. SCI P364 Steel Building Design: Worked Examples - Open Sections, 2009 (A 2017 revised edition is available from SCI)
41. Zuo, Wenkang, Man-Tai Chen, and Ben Young. "Structural behaviour of cold-formed steel elliptical hollow section stub columns after exposure to ISO-834 fire curve." Thin-Walled Structures (2023): 111309.