EKBAL MOHAMMED SAEED SALIH
AHMENOUDA AL-ROUBAIY
and
YASSER LOUY AZEEZ SALIH

Effect of hot impacts on the transformation of white cast iron: an analytical study

Heat treatments are the most common method of transforming or modifying the structure of white cast iron, where cementite tapes can be decomposed at high temperatures and over a long period of time, but these thermal treatments require special furnaces and a long period of time, as well as a high cost with major problems associated with these techniques. In this study, a mechanical thermal treatment is employed, which includes two basic stages, the first being heating at a certain temperature (1100°C) for a rather short period of time, then applying sequential strokes (one stroke or group of strokes) for a period not exceeding a few minutes. Samples are examined by meticulous microscopic inspection as well as by x-ray examination. The findings proved that heating for short or long periods of time and at (1100°C) is not sufficient to get rid of cementite tapes, as the structure remained white cast iron. The important matter here is that the effect of the hot impact on the transformation of white cast iron into grey is related to the formation ratio. In this regard, the results uncover that using hot impact and at the same temperature, but at higher rates of forming (i.e. greater than 70%) the structure is completely transformed into grey cast iron.

Keywords: *Heat treatment, analysis, hot impact, white cast iron, grey cast iron.*

1.0 Introduction

Cast iron is a type of ferrous alloy which typically contains carbon in a percentage greater than around (2.14 wt % C). Casting is the only way to produce it, which is why it is called cast iron [1]. In general, much of the cast iron contains carbon (3-4.5 wt% C) in addition to other casting elements [2]. Compared to steel, its ductility is often poor and typically created by blacksmithing or hot forming. In spite of this, cast iron has many benefits, including its low cost, low melting degrees (1140-1200ºC) relative to steel, high fluidity in wide and complicated casting molds, high wear resistance and high damping power in addition to high compressive strength and other qualities [3].

Cast iron has two basic types depending on the nature of the relationship between carbon and iron. The first is white cast iron, which is characterized by its hardness and high wear resistance, but is inoperable, and the second type is gray cast iron, which has better operational properties than white. The metallurgical characteristics exhibited by white is what has added certain qualities where carbon binds to iron forming a dense network of cementite (Fe_3C) and this compound is distinguished by high ductility with lost ductility. Therefore, this type of cast iron is inoperable and its uses are very limited, such as those used for crushing and grinding machines [4]. As far as gray is concerned, it has stronger working properties than white, since carbon here is free deposited in the form of thin flakes of graphite in pearlite, ferrite or even cementite floors, depending on the cooling factor associated with its deposition [5]. White cast iron, despite its high mechanical properties, its lack of ductility restricted its use [5].

Numerous studies have been conducted to study the effect of thermal treatments (being the only method) in modifying and changing the metallurgical structure of white in order to improve its properties, especially ductility, and convert it into cast iron malleable and ductile and at the same time retain other mechanical properties in a very reasonable manner. In this way, it is used in the automotive industry, wheel huts, fitting parts for petrol, water or air, as well as for the repairing of bicycle tires and parts of agricultural and textile machinery [6,7,8]. Heat treatments are the only method used to enhance the properties of steel. It requires heating stages, elevated temperatures for long stretches of time, and in special atmospheres for converting to cast iron paths. These treatments are distinguished by long durations, elevated temperatures, high costs, and the deficiencies and complications that surround them [9.10].

Sil'man et al. [11] studied the influence of thermal treatments on the structure and properties of white in the presence of elements such as (Mn, V). Stan et al. [12] employed the thermal analysis (cooling curve) to compare hypoeutectic grey (lamellar graphite) and ductile (nodular graphite) cast irons solidification patterns. In order to obtain a better experimental condition and improve surface hardness, García-León et al. [13] developed different thermal treatments

---

Messrs. Ekbal Mohammed Saeed Salih, Ahmenouda Al-Roubaiy, and Yasser Louy Azeez Salih, Materials Engineering, Department of Metallurgical Engineering, University of Babylon. E-mail: saeed_ekbal@yahoo.com

on nodular grey cast iron. Using thermo-mechanical treatment technology, Abdellah et al. [14] researched how enhance the ductility and flow behaviour of cast iron without change in the chemical composition.

Kante et al. [15] discussed the impact of low temperature annealing of cast irons on the combined electron beam in addition to nitriding treatments Jia et al [16] researched the impact of tempering (with in-situ analysis in multiple cycles) on resistance (wear, toughness and durability) by alternate water quenching and air cooling. As far as thermo-electric parameters are concerned, their effect has been observed, which involves hot shock in the attempt to curl white and transform it into red, thereby reducing the problems of conventional thermal treatments. Yamada and Kobayashi [17] investigated the thermomechanical treatment's effect on the hardness of rolled graphite cast iron and how the procedure's length values change.

The present study represents an attempt to transform white cast iron to gray with the help of mechanical thermal treatment, in which white and heated cast iron samples are exposed to (1100°C) and for a specific period of time, to direct knocking for a time or several times. Also, the effect of per cent formation percentages on the transformation process was studied through microscopy and x-ray examination.

2.0 Experimental procedures

White cast iron alloy was prepared from high purity metals and used induction furnaces for the smelting process and the temperature was (1398°C) and then poured into cylindrical sand molds with dimensions (30 mm in diameter and 70 mm in thickness). Table 1 shows the chemical composition of white cast iron used for this study.

Samples are heated up to (1000°C) for a period of (20) minutes in thermal treatment furnaces using Argon gas to prevent any subsequent oxidation and then divided into four groups. Samples are prepared for accurate microscopic examination, hardness measurement and x-ray examination. Preparation processes included (cutting, smoothing, polishing and exposure), the picral solution used consisting of (4%) picral acid in ethanol and as specified (ASTM SE407). Fig.1 shows the exact crystal structure and Fig.2 shows x-ray examination of the base sample prior to treatment. The average hardness is (470HB).

The stability of the samples is tested against carbonation, the second group of samples is heated at (800, 950, 1000°C) and for a time of between 15-240 min. All samples showed an accurate crystalline structure very similar to the original samples (without annealing), as there is no change in the exact composition, which means that no change from white to grey occurred completely or even localized. The only change that occurred on the surface is the carbon removal process because the heating process was not isolated from the normal atmosphere as shown in Fig.3.

As for the third group, the samples are heated to temperatures (1100°C) and for periods ranging from (60-120 min.). As well as, the exact composition is examined, which also looked similar to what is in the original samples and is also free from any transformation (Fig.4).

Experiments have shown that white cast iron is stable up to (1100°C) and for the period indicated. As for the fourth group, the samples are heated at the same temperature (1100°C) for a period of (10) min, followed by taking the sample out of the oven and knocking it directly for one or more times using a hydraulic hammer, as shown in Fig.5; hammer specifications, followed by measuring the percentage for formation are as shown in Table 2.

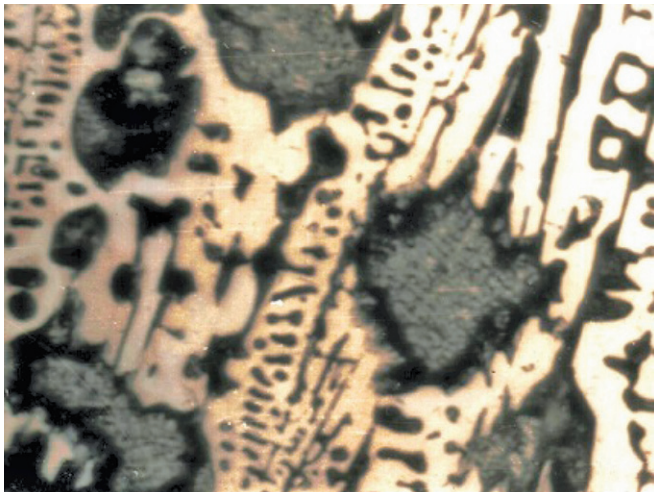

Fig.1 The exact crystal structure

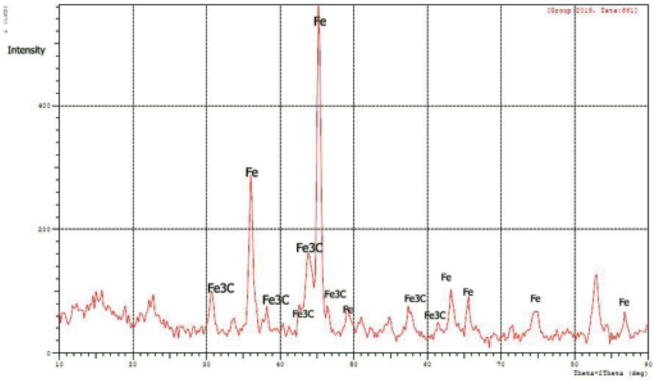

Fig.2 X-ray examination of the base sample before the heat agent

TABLE 1: CHEMICAL COMPOSITION OF WHITE CAST IRON

Fe%	C%	Si%	Mn%	Cr%	P%	S%	O_2%
Rem.	4.2	0.61	0.8	–	0.008	0.014	0.002

Table 2: Percentage for formation of white cast iron

Alloy	Operation conditions					% Formation $=100\ x\ \frac{L_{\circ}-L}{L_{\circ}}$
	Hammer name	Fallen hammer weight	Maximum power in one stroke	Number of hammers/min	Horsepower kW	
1						20
2						45
3	Pneumatic hammer	165	270	190	24.11	60
4						70>

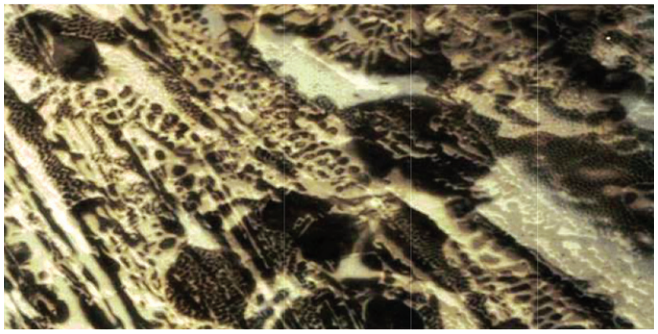

Fig.3 The stability of samples after heating

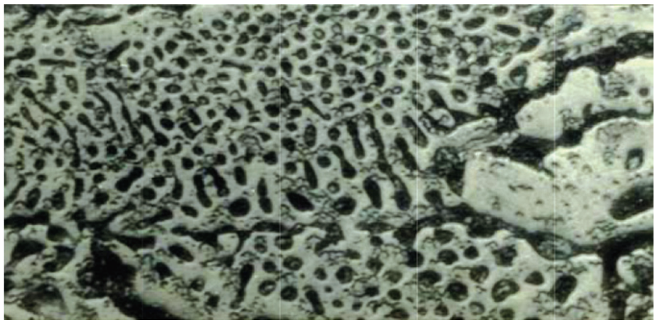

Fig.4 The crystal structure of white cast iron after heating (1100°C) and for a period of (60-120min)

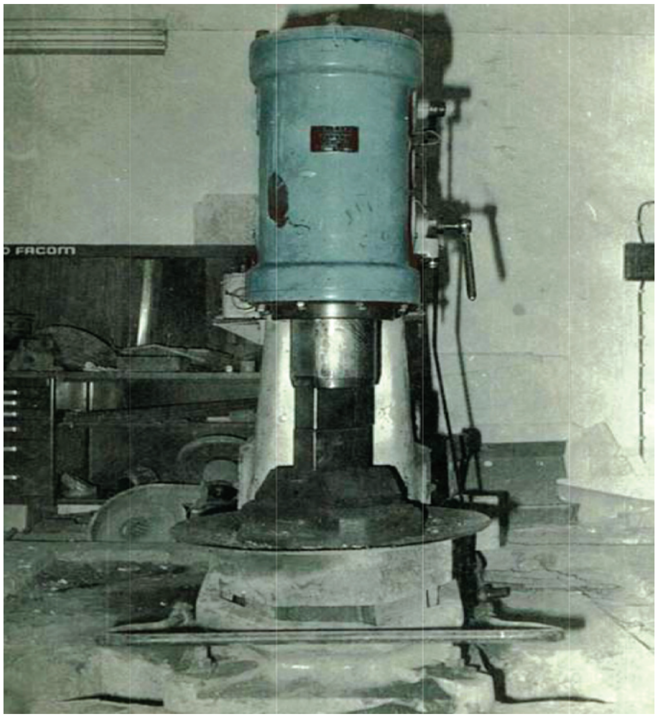

Fig.5 Hammer used in white cast iron methods heated at 1100°C for a period of 10 min.

Fig.6 Model of the structure of cast iron at low forming ratios

By examining the crystalline structures of the fourth group and the different forming ratios from (20%) to (60%), it is observed that the synchronization of the annealing and forming processes is accompanied by a deformation of the fine composition of the sample without causing carbonation (Fig.6). And that there is a change in the pattern of cementite (Fe_3C) distribution, where the lamellar shape turns into something similar to the mass at (60%) as shown in Fig.7, which represents a change in the pattern of cementite distribution with an increase in the formation ratios in the white cast iron and x-ray examinations.

When the percentage of formation increased by (greater than 70%), a major shift occurred, as a complete and clear transformation from white cast iron to grey is observed, the graphite flakes appear to be completely clear as shown in Fig.8.

3.0 Results and discussion

The current research reflects a new approach for turning white cast iron to grey and a process that can be described as simple and quick compared to conventional heat treatment methods. Also, this approach will shed light on the stages of the carbonation mechanism, from the figures (1, 3, 4) it seems

Fig.7 Model of the structure of white cast iron at the forming ratio (60%)

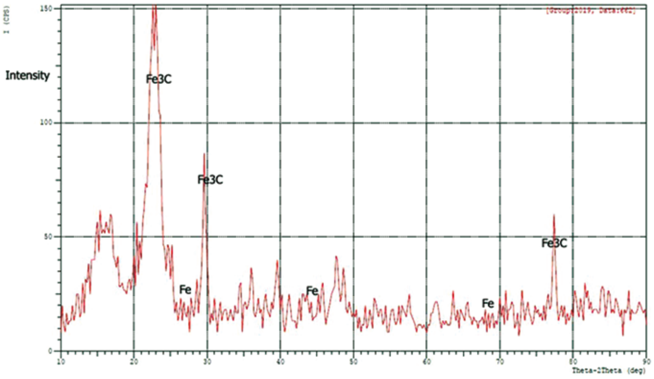

Fig.8 X-ray analysis of the white cast iron structure model at the forming ratio 60%

obvious that white cast iron cannot turn grey at the temperature (1100C°) and with the annealing times (60-120 min.). It is also assumed that the coordination of the annealing and shaping processes is followed by a deformation of the fine composition and does not induce any carbonation as shown Figs. (7, 6). But when the formation percentages increase larger than (70%), a sudden big change will occur (Fig.9). Through Fig.7, important results can be reached:

The first is that there seems to be a complete and absolute change from white cast iron to grey, and it happens when some percentages of the composition are surpassed (more than 70%). The second is that the factors influencing the transformation process (carbonation) are very significant in the understanding of the transformation system since it is not possible to focus entirely on correct microscopic inspection.

These findings are consistent with previous research in which a rapid and complete transition from white to grey happens at a development rate of more than (72%) [11,15]. The research discussed the most important factors concerning the carbonation function. It is known that this mechanism goes through (4) stages, which are: the time of the melting of cementite in Kama iron, the time of the movement of carbon atoms through iron and the crystallization of graphite, and finally the distribution of iron and silicon atoms away from graphite. It was assumed that the diffusivity regulates the mechanism of transformation, that the diffusivity of iron and silicon and all other elements present cannot be the control factor in the process, as the activation energies of these elements in austenite have the same number, whereas the activation energy for carbon diffusion is the lowest. When measuring the diffusion distance [L] for (Fe, C) from the equation:

Fig.9 The white cast iron was largely grayed after high forming rates

$$L = \pi\sqrt{Dt}$$

At a temperature (1100 C°), where (D) is the coefficient of diffusion, as is shown in Table 3 (11).

Through these values, it can be inferred that the carbonation process is at (1100°C) and takes place within a few minutes and is finished within (30 min.). While we did not note any phase of its carbonation in the above-mentioned temperature range over any period of time (15-240 min.) the volume of cementite had increased. It can be inferred from this that the diffusivity element of carbon or iron is not the primary factor in the carbonation process.

As for the crystallization of graphite, this can also be omitted as a limiting element in the process of transformation. This finding is consistent with previous studies [16, 17] that the growth rate is steady and continuous and moves from the point of origin, i.e. when the annealing time is zero (Zero time)

TABLE 3: DIFFUSION DISTANCE AT (1000C°) [11]

Elements	$D^oCm^2s^{-1}$	Q. Kcal mol^{-1}	$X = \pi\sqrt{D_\circ}\exp\left(\frac{-Q}{KT}\right).t, cm$		
			5s	5min.	3hr
C	0.01	27.0	5×10^{-3}	3.9×10^{-2}	2.3×10^{-1}
Fe	58	74.2	6.6×10^{-5}	5.1×10^{-3}	3.1×10^{-3}

it is considered to be the beginning of the transition (Zero time is considered to be the beginning of the reaction), but in the functional application, it did not find any change. Indeed, no procedure was conducted in this study when heated at (1100°C) either for long or short periods of time.

The melting stage of cementite in austenite is known to regulate the mechanism of carbonation. Melting happens (immediately) at some percentages by hot impact formation (high forming ratio). The explanation is attributed, first of all, to the crystal composition of cementite and to the existence of the bonding between the atoms in the cementite crystal itself. Numerous experiments have shown [18] that the crystal structure of cementite is distinguished by the presence of two forms of bonds. The first is the bond between (Fe-C) which is covalent and the second between (Fe-Fe) which is metallic in nature. It is understood that the covalent bond is double the strength of the mineral bond, in addition to the fact that the crystal structure of cementite contains a group of prisms; the internal bond in it is covalent, while the prisms are linked by the mineral spur [19]. The metal band enables the plastic shaping mechanism so that the prisms can move through the creation while maintaining the covalence intact within them (thus the prisms do not break). The forming can take place if the sliding is at (010) levels.

This can be derived from the existence of the structure of the layers of atoms inside the prisms. This ability is consistent with what other researchers have recorded [20,21] and thus, due to the low rate of forming of cementite crystals due to hot shocks, there could be a mutual movement of prisms at levels (010) while the interconnection between these prisms remains intact. But when the deformation ratios reach a certain limit, the covalent bond (within the prisms) would not be able to tolerate and break down. This describes the quick and wide breakdown of cementite and the abrupt introduction of carbonation.

4.0 Conclusions

Presented study conclusions can be drawn as follows:

i. Temperature annealing (1100°C) for a 60 min does not induce any total or even localized carbonation phase.
ii. The formation resulting from hot impact and even at low forming concentrations does not induce any total or even localized carbonation.
iii. When the shape resulting from the hot impact reaches those limits (greater than 70%) in significant quantities; a rapid and complete transition phase takes place from white cast iron to grey.
iv. The main element in the transition process is the solubility of cementite in the Kamairon.
v. The cause of the abrupt transition can be traced to the breaking of the covalent bond, which is no longer capable of preventing the creation of hot impacts so that these covalent bonds are broken, leading to a high solubility of carbon and its migration.

References

[1] Ibrahim, K. M., and Ibrahim, M. M. (2014): Heat treatment in high chromium white cast iron Ti alloy. *Journal of Metallurgy*, *2014*.

[2] Farah, A. F., Crnkovic, O. R., and Canale, L. C. F. (2001): Heat treatment in high Cr white cast iron Nb alloy. *Journal of materials engineering and performance*, *10*(1), 42-45.

[3] Filipovic, M., Kamberovic, Z., Korac, M., and Gavrilovski, M. (2013): Microstructure and mechanical properties of Fe–Cr–C–Nb white cast irons. *Materials & Design*, *47*, 41-48.

[4] Keil, B., and Devletian, J. (2011): Comparison of the mechanical properties of steel and ductile iron pipe materials. In *Pipelines 2011: A Sound Conduit for Sharing Solutions* (pp. 1301-1312).

[5] Razumakov, A. A., Stepanova, N. V., Bataev, I. A., Lenivtseva, O. G., Riapolova, I. I., and Emurlaev, K. I. (2016): The structure and properties of cast iron alloyed with copper. *Materials Science and Engineering*, 124, 012136.

[6] Herring, D. (2014): *Atmosphere Heat Treatment: Principles, Applications, Equipment*. BNP Media.

[7] Walton, C. F. (Ed.). (1971): *Gray and ductile iron castings handbook*. Gray and Ductile Iron Founder's Society Incorporated.

[8] Chakrabarty, I. (2017): 2.10 Heat Treatment of Cast Irons.

[9] Boccardo, A. D., Dardati, P. M., Celentano, D. J., and Godoy, L. A. (2017): Austempering heat treatment of ductile iron: Computational simulation and experimental validation. *Finite Elements in Analysis and Design*, 134, 82-91.

[10] Sil'man, G. I. (2005): Alloyed white iron with composite structure. *Metal science and heat treatment*, 47(7-8), 343-348.

[11] Sil'man, G. I., Frol'tsov, M. S., and Bolkhovitina, N. A. (1976): Effect of heat treatment on the structure and properties of alloyed white cast iron. *Metal Science and Heat Treatment*, 18(2), 121-123.

[12] Stan, S., Chisamera, M., Riposan, I., Stefan, E., Neacsu, L., Cojocaru, A. M., and Stan, I. (2019): Simultaneous thermal and contraction/expansion analyses of cast iron solidification process. *Journal of Thermal Analysis and Calorimetry*, 138(4), 2529-2540.

[13] García-León, R. A., Acevedo-Peñaloza, C.,and Quintero-Quintero, W. (2020): Mechanical evaluation of the nodular gray cast iron with the application of

thermal treatments. *Journal of Xi'an University of Architecture & Technology*, 12, 1868-1876.

[14] Abdellah, M. Y., Hassan, M. K., and El-Ainin, H. A. (2014): Plasticity and formability controlling of cast iron using thermo-mechanical treatment. *American Journal of Materials Engineering and Technology*, 2(3), 38-42.

[15] Kante, S., Leineweber, A., Holst, A., and Buchwalder, A. (2019): Low temperature annealing and graphitizing of white solidified low alloy cast irons. *Materialwissenschaft und Werkstofftechnik*, 50(6), 682-695.

[16] Jia, X., Huang, Y., Zuo, X., Liu, Y., Chen, N., and Rong, Y. (2019): High hardness-toughness and wear resistance of white cast iron treated by a multicycle quenching-partitioning-tempering process. *Heat Treatment and Surface Engineering*, 1(1-2), 57-62.

[17] Yamada, S., and Kobayashi, T. (1997): Effect of Thermomechanical Treatment on Toughness of Spheroidal Graphite Cast Iron. In *Advanced Materials Research* (Vol. 4, pp. 195-202). Trans Tech Publications Ltd.

[18] Collin, N. (2014): Thermo-mechanical fatigue of cast iron for engine applications.

[19] Hendricks, S. B. (1930): XXXVI. The Crystal Structure of Cementite. *Zeitschriftfür Kristallographie-Crystalline Materials*, 74(1-6), 534-545.

[20] Flinn, R. A. (1975): Engineering Materials and their Applications (Houghton Mifflin). *The University of Newcastle 142*.

[21] Schastlivtsev, V. M. (2005): Crystal structure of cementite. *Bulletin of the Russian Academy of Sciences: Physics*, 69(9), 1447-1452.

PERFORMANCE STUDY OF SINGLE CYLINDER ENGINE DUAL FUEL (DIESEL + LPG)

(Continued from page 340)

[17] Vinoth, T., Vasanthakumar, P., Krishnaraj, J, Arunsankar, S.K.. Hariharan, J. and Palanisamy, M. (2017): "Experimental Investigation on LPG + Diesel Fuelled Engine with DEE Ignition Improver," *Mater. Today Proc.*, vol. 4, no. 8, pp. 9126–9132.

[18] Rao, G. (2010): "Performance evaluation of a dual fuel engine (Diesel + LPG)," vol. 29, no. 14, pp. 235–246.

[19] Oester, U. and Wallace, J.S.(1987): "Liquid propane injection for diesel engines," *SAE Tech. Pap.*

[20] Ashok, B., Ashok Denis, S. and Ramesh Kumar, C. (2015): "LPG diesel dual fuel engine - A critical review," *Alexandria Eng. J.*, vol. 54, no. 2, pp. 105–126.

[21] Yuvaraj, M. (2018): "Performance and Emission Characteristics of a Diesel-LPG Duel Fuel in Greeves Engine," no. November.

[22] Rosha, P., Bharj, R.S. and Gill, K.J.S. (2014): "Performance and emission characteristics of Diesel + LPG dual fuel engine with exhaust gas recirculation," *Int. J. Sci. Eng. Technol. Res.*, vol. 3, no. 10, pp. 2570–2574.

[23] Wei, M., Li,, S., Liu, J., Guo, G., Sun, Z. and Xiao, H. (2017): "Effects of injection timing on combustion and emissions in a diesel engine fueled with 2,5-dimethylfuran-diesel blends," *Fuel*, vol. 192, no. 8, pp. 208–217.

[24] Anye Ngang, E. and Ngayihi Abbe, C.V. (2018): "Experimental and numerical analysis of the performance of a diesel engine retrofitted to use LPG as secondary fuel," *Appl. Therm. Eng.*, vol. 136, pp. 462–474.

[25] Goto, S. and Lee, D. (2018): "SAE TECHNICAL Development of an LPG DI Diesel Engine using Cetane Number Enhancing Additives," no. 724.

[26] Cao, J., Bian, Y., Qi, D., Cheng, Q. and Wu, T. (2004): "Comparative investigation of diesel and mixed liquefied petroleum gas/diesel injection engines," *Proc. Inst. Mech. Eng. Part D J. Automob. Eng.*, vol. 218, no. 5, pp. 557–565.

Printed by Pradip Kumar Chanda at The Indian Press Pvt. Ltd. 93A Lenin Sarani, Kolkata 700 013 and
published by him for Books & Journals Pvt. Ltd. from 62 Lenin Sarani, Kolkata 700 013.