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International Journal of
Materials Technology and Innovation
Volume 3, Issue 1 (2023), pages 57-69

IJMTI
Online ISSN 2682-4299

An overview of Thin Wall Cast Iron Castings and its Applications in Automotive Industry

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Received 11 September 2022
Accepted 27 October 2022
Published 6 April 2023

Abstract

Recently, the designer of automotive components has been focused their efforts on the production of thin-walled cast iron castings (TWCI) to save energy and materials. There has been an increase recently in requests for TWCI with a wall thickness lower than 3 mm yielding high strength-to-weight ratios. The development of thin wall technology will permit the automakers to make a better choice among competing materials and TWCI with its different types (DI, ADI, S,iMo DI, and Vermicular graphite iron), thus reducing the total cost of the vehicle. The effect of various parameters to produce sound and free-carbides ductile iron castings was discussed. The parameters included molding materials, chemical composition, pouring temperature, types of inoculants and their amount as well their austempering treatment parameters for ADI and other foundry basic practices. New trends and developments of thin wall castings for four grades of iron casting have been reported. The four grades are: ductile iron for primary pump bodies, ADI for gears and hollow connecting rods, heat-resistant SiMo for exhaust manifolds, and finally vermicular graphite iron for heads and brake systems. Some of the successful applications for the four grades of TWCI especially in the automotive applications were reported. Recent research work at CMRDI has revealed that carbide-free thin wall cast iron plates (3mm thick) made of DI, ADI, and SiMo DI could be produced by controlling the parameters mentioned above.

Keywords: Thin-wall cast iron, ADI, SiMo, Vermicular cast iron

1. Introduction

Recently, the need to save energy and resources has forced designers to a focus on lightweight casting. In the automotive industry, the most effective way to reduce vehicle emissions is to improve the combustion cycle and make cars lighter. Hornung [1] estimated that reducing vehicle weight by 100 kg results in fuel savings of 0.5 to 1 liter. Automakers are turning to new technologies to make cars lighter and subsequently lower fuel consumption. Recently, thin wall ductile irons (TWDI) are considered an alternative material for light alloys (Al alloys, Mg alloys, and composites) related to their properties such as high strength and ductility [2], high wear and impact resistance, and very good machinability and castability [2-4]. In the past, thin wall castings were used in the automotive industry for components such as the engine block, cylinder head, and outlet manifold with a wall thickness of less than 6 mm. Then the thickness requirement gradually decreased to a thickness of less than 5mm and finally 4mm. Today, components with a thickness of less than 3 mm can be found in automotive components, and thin light-duty parts with 1 or 2 mm in thickness produced by casting like manifold are under investigation [5].

Automakers always aim to select the most suitable material based on cost/material properties considerations. The technology developed in the field of thin wall casting will let the automakers to do better-informed choices between TWCI and the other competing materials to reduce the total cost of the cars. Stefanescu [6] who proved that ductile iron offers advantages over aluminum, especially if thin ductile iron parts can be produced in the as-cast state.

IJMTI vol. 3, issue 1 (2023) 57-69 https://doi.org/10.21608/IJMTI.2022.153909.1056

According to mechanical properties, Fig.1 shows a comparison between Al alloys and cast iron in the specific mechanical properties (property-to-density ratio). (Fig. 1a-c) can be demonstrated that an iron casting can be obtained with the same weight as aluminum, and it will have similar tensile strength, yield strength, and stiffness (assumed to have a ratio of yield strength to Young's modulus E) and/or elongation higher. Austempered ductile iron (ADI) is an exception in these comparisons that has superior properties compared to any Al-alloys. As shown in (Fig. 1d) aluminum alloys have no endurance limit, therefore require an increase in size to hamper fatigue failure of critical body and chassis components. Therefore, it is clear that cast iron has favorable relative properties (property/density) similar to aluminum alloy. Moreover, cast iron has higher strength at high temperature comparing to Al-alloys. It was found from Fig. (1e) that above 100ºC the relative strength of Al- alloys decreases sharply. On the other hand, above 200ºC the relative strength of DI with a pearlitic matrix surpasses the relative strength of Al-alloys. Wear properties are an important factor that needs to be considered in the casting design. Cast iron is characterized by the ability to surface hardening which is not found in Al or Mg alloys without additional processing resulting in expensive layers.

Economically, the low production costs of cast iron make it favorable material compared to other materials (Fig.2). In some parts a high-temperature mechanical integrity is required such as in housing of catalyst, internal combustion engine, and exhaust manifolds. Other cases need higher mechanical properties (high strength to weight ratio, fatigue, wear resistance, elongation) such as crankshafts, gears, railway engineering, heavy truck, transmissions, suspensions, and bracket trailer etc. Therefore, it is important to develop novel grades of iron castings with specific properties that add to the performance in particular applications. These novel grades involved ADI with its unique combination of mechanical properties and SiMo with its oxidation resistant properties as well as vermicular graphite with its good vibration-damping capacity and thermal conductivity.

The objectives of the current review are to review different investigations carried out in the production of thin wall castings of four cast iron alloys (ductile iron, Si-Mo ductile iron and ADI as well as vermicular graphite iron) and highlights its applications for every type of cast iron. The work initially deals with the several parameters which are responsible for carbide formation in thin wall cast iron such as molding material (cooling rate), the inoculation practice, chemical composition, austempering treatment for ADI and Mg treatment for vermicular graphite iron as well as other foundry basic practices.

2. Casting of TWDI

TWDI is characterized by high cooling rates which lead to the following casting defects:

- Misrun during pouring in the mold because the melt solidifies before end of mold filling
- Carbides formation during solidification (high cooling rate does not allow time for graphite nucleation).

The fast cooling of TWDI castings needs special attention to produce carbide-free castings [2, 8-13] which will be discussed below.

2.1. Properties of the mold

There are several restrictions during the production of thinner parts. DI microstructure is affected by the cooling rate during solidification. Greater cooling rates enhance the precipitation of eutectic ledeburite (cementite and austenite). The presence of carbide in DI microstructure is severely harmful to its mechanical properties and processing. Moreover, the higher cooling rate will produce a high nodule count which is considered as important factor in the microstructure of DI and significantly affects its mechanical properties [14]. A published work has shown that the mechanical properties of TWDI castings are limited by the high nodule count (1000 and more) achieved in the castings [15, 16]. Showman and Afterheide [17] showed that changing the thermal properties of the mold can be controlled the nodule count to a lower level.

The thermal properties of the mold will have a great effect on the cooling rate. Therefore, the casting could be enhanced by lowering the thermal conductivity and heat capacity of the mold. For example sand molds will have a higher tendency to carbide formation than CO_2 bonded silica sand [18]. Reducing the sand grain size can also reduce the tendency of carbide formation [18]. The use of graphite-based zircon coating acts as a thermal barrier between the solidified metal and the mold sand. Therefore, the addition of insulating materials to the green sand can reduce the cooling rate [5]. It was mentioned that the coating of the mold has a great effect on the mechanical properties of TWDI compared to sand grain size [5]. Another example of reducing cooling rate is using low-density alumina

IJMTI vol. 3, issue 1 (2023) 57-69 https://doi.org/10.21608/IJMTI.2022.153909.1056

silicate ceramic (LDASC), which has lower density and thermal conductivity [20].

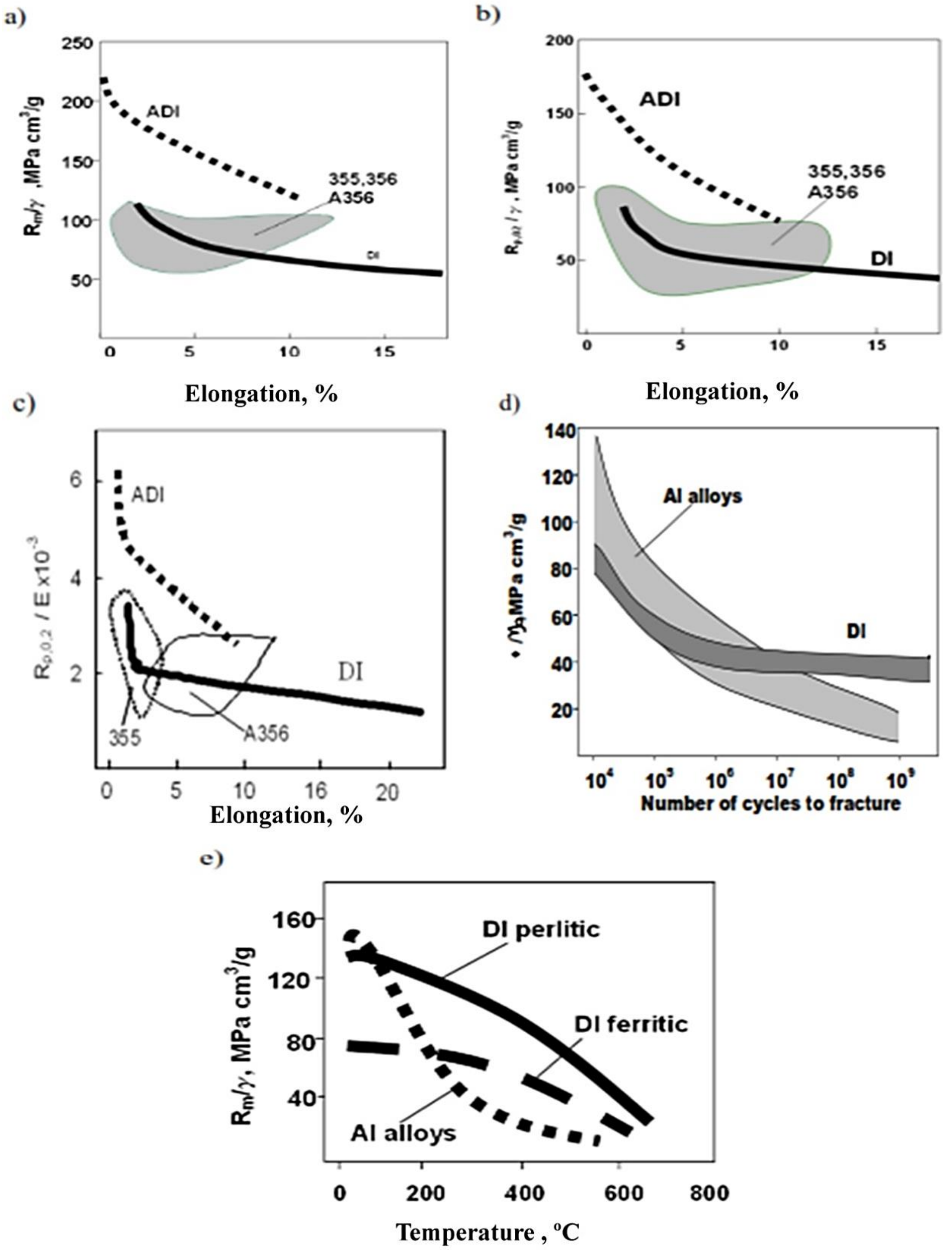

Fig. 1 a) Tensile strength, b) yield strength, c) stiffness, d) fatigue strength and e) high temperature strength [2].

IJMTI vol. 3, issue 1 (2023) 57-69 https://doi.org/10.21608/IJMTI.2022.153909.1056

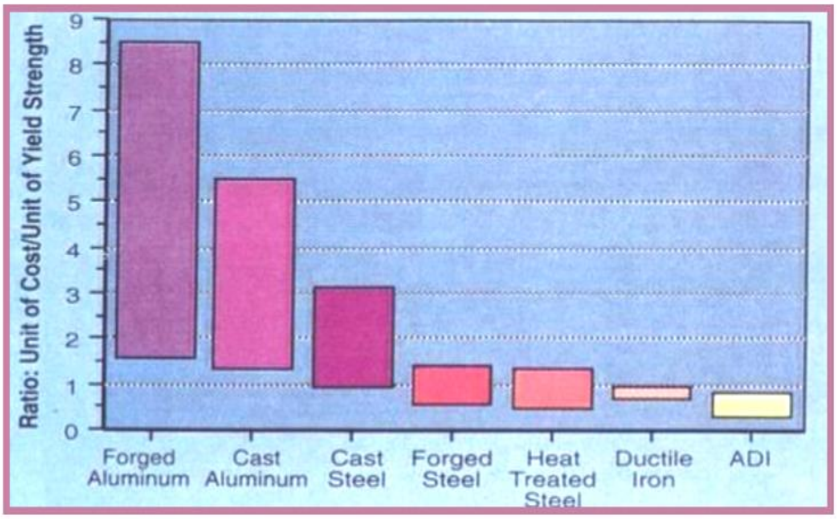

Fig. 2 Costs of different materials for obtaining unit of yield strength [7].

The thermal properties of the molding materials have a great effect on the castability of cast iron. Figure 3 shows the castability of spirals thin wall cast iron with 3mm wall thickness poured into three different molding materials [silica sand (classical), self-hardening molding the sand (SHMS) and SHMS with LDASC]. The figure shows that, in case of pouring 3 mm wall thickness spiral cast iron into SHMS with LDASC sand, the whole spiral cavity (1500 mm) was completely filled. It means that castability for the SHMS and SHMS with LDASC is higher than for silica sand (classical), Fig. 3. The main reason for this difference is the ability of material mold to absorb heat. M. Górny [12] reported that molding materials have a great effect on the structure parameters (graphite nodule count, ferrite and cementite fraction) of thin wall DI castings. Where the graphite nodule count decreased by 30% and also ferrite volume fraction increased by twice times by using molding material containing LDASC sand comparing with classical silica sand. As a result, substituting sand with LDASC, using of fine grain size sand and mold coating will reduce carbide formation and enhance mold filling.

2.2. Pouring rate

Rapid filling of the mold can reduce heat loss during mold filling. This requires a short and good gate system [21]. Proper mold ventilation is also necessary to remove air from the mold cavity [22].

2.3. Pouring temperature

Increasing of pouring temperature will decrease the cooling rate due to more heat must be taken away from the casting. Generally, the optimum pouring temperature for TWDI is between 1400-1450ºC [18, 23-25]. The high pouring temperature results in Mg fading, because of Mg evaporates at an elevated temperature. At 1480ºC, Mg-content fades with 0.001% / min, which makes it hard to control the Mg% and thus the fine structure of the casting. [25]. Excessive heat of the molten metal above 1480 °C will have a bad effect on the graphite nucleation [22] and give a poor response to inoculation. [26]. A. Trytek et al. [27] reported that the higher pouring temperatures combined with the force of the liquid metal stream results in erosion of the molding sand, scabs, sand buckles, dirt spots, etc. To prevent the presence of undesired features in thin sections it should control the binding materials and coatings of the mold as discussed above as well as pouring temperature [28-30].

2.4. Chemical composition

The vital issue through the solidification of TWDI is the nucleation of graphite to avoid carbide precipitation. This can be fulfilled by increasing Si and C contents by maximizing the efficiency of inoculation (Fig.4). It is preferable to use hypereutectic alloys (CE: 4.4- 4.6%) in order to maximize castability and assure complete mold filling [31].

IJMTI vol. 3, issue 1 (2023) 57-69 https://doi.org/10.21608/IJMTI.2022.153909.1056

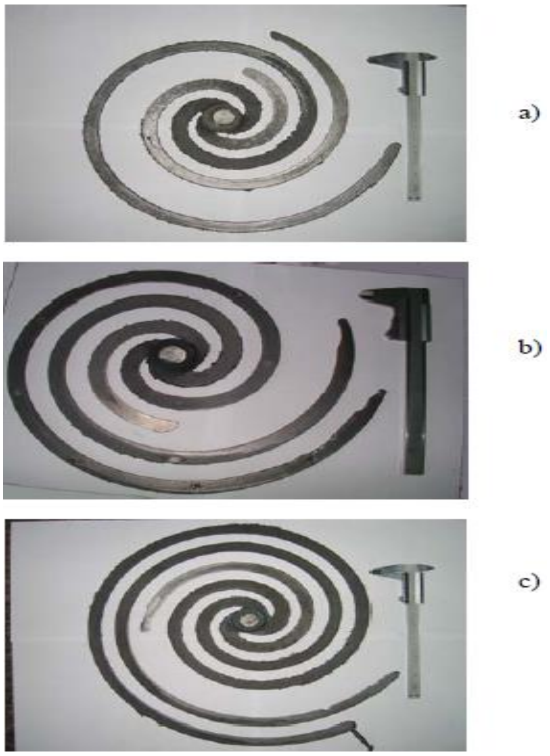

Fig. 3 Castability of spirals of 3mm wall thickness poured into mold with different molding materials: classical a), SHMS b) and SHMS with LDASC c) [12].

Too high CE may lead to lower mechanical properties and higher tendency for gas defects, whereas too low CE will induce shrinkage porosity. Moreover, it is preferable to limit Si content to avoid its harmful effect on the elongation. Furthermore, high Si reduces toughness, reduces thermal conductivity and raises the brittle fracture transition temperature.

The strategies to minimize carbide precipitation include controlling the chemical composition of DI and minimizing the content of carbide formers such as Cr, Mo, V, Ti and W. These elements segregate towards the cell boundary and at the middle of the casting in the last freezed material [32]. Mg as nodularizing element should be kept at a low level as well (0.025-0.035%), because it has a carbide stabilizing effect [24, 33]. In the case of TWDI, the high solidification rate during solidification is the main factor that promotes carbide precipitation. Therefore, to produce TWDI components, it is preferable to use unalloyed DI.

2.5. Inoculation

The inoculation process has vital importance in the production of high- quality cast irons. Inoculation inserts additional nuclei for graphite precipitation and lowers the under-cooling and subsequently carbides formation [34, 35]. Appropriate melt treatment including efficient inoculation and nodularization are essential in the production of sound TWDI castings. There must be synergy between inoculation and nodularization treatments to produce a high graphite nodule count with good nodularity and carbide-free TWDI. Mg treatment (nodularization) is achieved first followed by an inoculation process. Mg treatment is responsible for changing the shape of flake graphite to spheroids which give ductile iron its particular properties.

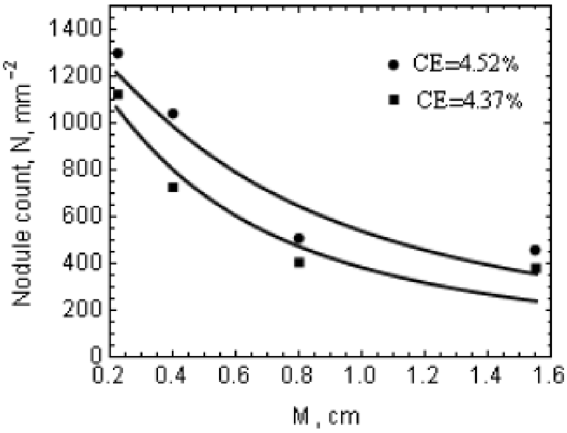

Fig. 4 Nodule count for different values of carbon equivalent (CE), CE = C + 0.33Si [8].

In addition, the nodularizing treatment is also a part of inoculation where it results in tiny inclusions that act as nucleation particle for graphite [36]. Inoculation is followed directly to enable heterogeneous nucleation to increase the nodule count and prevent carbides formation. As shown in (Fig.5a), the effectiveness of inoculation vanishes with time and more than half of its effectiveness is lost in the first 5-7 minutes [37]. Therefore, the use of “late inoculation” both in the stream during mold filling and in the mold is necessary.

Before the nodularizing treatment, it is important to keep sulphur content very low in the melt (0.01% ≤ S ≤ 0.03%) [38]. Increase in inoculation percentage results in an increase in the nodule count and ferrite volume fraction. Furthermore, some grades of inoculants that contain elements such as RE, Bi, Sr, S, O are more powerful in eliminating carbide formation and increasing nodule count in TWDI (Fig.5b).

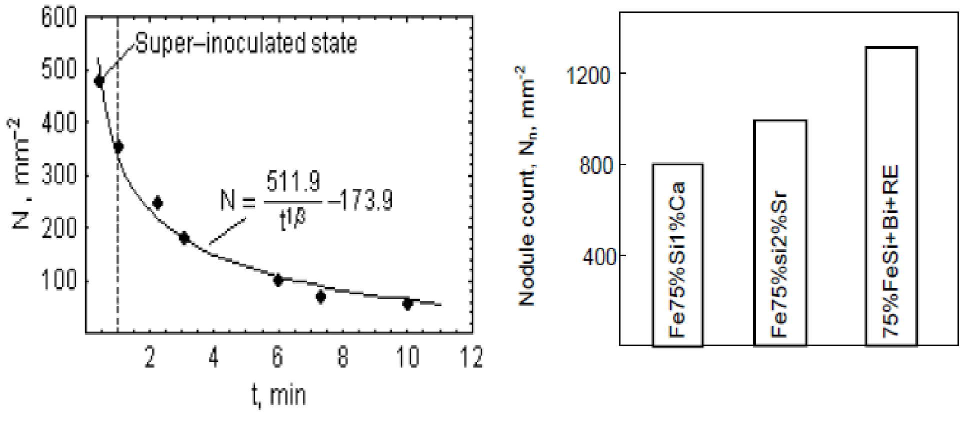

Fig. 5 Nodule count versus time after inoculation (a) and nodule count for various types of inoculants (b) [8]

3. Thin wall austempered ductile iron (TWADI)

ADI is the fastest growing region in casting technology. ADI is the materials which offer the design engineer with the best combination of low cost, high strength to weight ratio, design flexibility, good machinability as well as good toughness and wear resistance [39]. It is an interesting class of materials due to its unique microstructure and interesting properties. By applying austempering treatment, ductile iron matrix will transform to acicular ferrite and stabilized austenite instead of ferrite and carbide as in austempered steels. The excellent combination of its mechanical properties is related to the stabilized austenite [40, 41]. This microstructure allows ADI to compete forging steel and other engineering alloys in terms of mechanical properties, weight saving and low production cost.

Figure 6 shows the competition of ADI with steel in strength for a given level of elongation. The figure does not offer the relative density of the materials in the comparison. DI and ADI are lower in specific weight by 8-10% than wrought steel. So, if the component stiffness is enough and a steel part can be replaced with an ADI component of the exact same design, the part will be 8-10% less in weight [42].

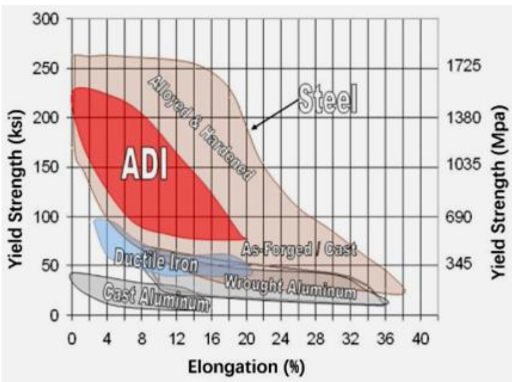

Fig. 6 Yield strength of ADI versus that of various engineering materials [7]

3.1. Parameters affecting production of high-quality thin wall ADI

The factors that affecting successful production of high -quality ADI are well established, while the factors that affecting the production of TWADI are still under investigation [43]. However, the use of ADI in thin-walled and high-strength parts has been mentioned in a very limited number of references [42, 44, 45]. Martinez et al. [44] reported that the two-cylinder, racing-car front-wheel hollow

IJMTI vol. 3, issue 1 (2023) 57-69 https://doi.org/10.21608/IJMTI.2022.153909.1056

connecting rod is made from thin-walled ADI, confirming ADI's ability to build complex thin-walled high-strength parts. By controlling inoculation practice, chemical composition and molding materials it became possible to cast TWDI parts completely free from carbides. All of these parameters are discussed in the previous section of TWDI and should be considered when dealing with ADI.

3.1.1. Chemical composition

In large-section castings, segregating alloying elements like Mo and Mn is hard to avoid. As a result, an inhomogeneous structure is obtained. In TWDI castings, segregation of alloying elements is minimal and subsequently, the structure is more homogeneous. The homogeneous structure, high cooling rate, and nodule count of TWDI allow the addition of alloying elements such as Cu and Ni to be removed to enhance austemperability. Accordingly, TWDI is an ideal material in TWADI production without the addition of expensive alloying elements and long heat treatment times. [46].

3.1.2. Austempering treatment parameters

The subsequent heat treatment process required for obtaining the austempered structure will need special precautions when producing thin wall ADI. The atmosphere in the austenitizing furnace should be strictly controlled to prevent any surface decarburization of TWDI castings, which will lead to the formation of a ferritic surface layer. The influence of this layer on the mechanical properties is more pronounced in thin wall rather than regular ADI.

As mentioned before, the higher nodule counts in TWDI will reduce the carbon diffusion distance from the matrix to the nodule. This can greatly increase the rate of solid-state transformations in austempering treatment, i.e., austenite formation during austenitization treatment and ferrite formation during austempering. Furthermore, transformation kinetics are expected to be faster (reduce austempering time) and the minimal microsegregation in the matrix will participate in removing unreacted austenite areas at the last to freeze region. Consequently, the final microstructure is finer and more homogeneous and possibly has better mechanical properties than those of thicker ADI parts. Moreover, the austempering time required to obtain optimum mechanical properties may differ from the time measured for normal ADI. E. Fraś and M. Górny [46] showed that in TWDI castings (2mm) austempering for 5 minutes at 400° C is sufficient to obtain an ausferrite structure.

4. Thin wall Si-Mo ductile cast iron

The requests are increasing for high temperature materials that require high thermal expansion, microstructural stability and higher internal combustion engine operating temperatures. Moreover, these requirements cause the industry to tighten microstructure specifications to ensure thermal stability for certain applications. SiMo ductile cast irons are widely used in turbochrger and exhaust manifold applications, owing to a combination of superior oxidation resistance and thermal fatigue as failure modes [47-50].

As shown in Fig. 7, the microstructure of SiMo ductile iron composed of sheroidal graphite in a matrix of ferrite and stable M_6C carbides (M=Fe, Mo, Si) in the intercellular regions [47,48]. At certain cases, Si-Mo ductile iron provides a feature over high-Si ductile iron containing pearlite. This feature is the absence of pearlite and the existence of a thermally stable Fe_2MoC/M_6C-type phase, leading to dimensional stability at high temperatures, which means lower thermal stress.

Different types of Si-Mo alloys have been developed by varying the amounts of Si and Mo. M. Stawarz [51] has divided the specific application of SiMo into three categories according to molybdenum content in SiMo. Where, up to 0,5% Mo for applications with large and fast cycling temperatures and 0,5-1,0% Mo for applications with creep (long time in high temperature) as well as 1,5-2,0% Mo for applications requiring high strength at high temperature. The addition of up to 1% molybdenum is typical. More Mo may segregate as carbides at the grain boundary and result in lower toughness. The high Si content (4-6 wt. %) enhances corrosion resistance at high temperature and stabilizes the ferritic matrix, by increasing the A_1 temperature. Silicon content is normal up to 5%, but increasing Si content will improve oxidation resistance and strength at the expense of toughness and machinability. SiMo is cost-effective alloy when used in temperatures between (650 -870°C), which is popular choice for turbocharger housing and exhaust manifold (Table-1). When the exhaust temperature is increased, SiMo ductile iron shows limitation and thus manufacturers will use an expensive austenitic ductile iron called Ni-resist DI.

IJMTI vol. 3, issue 1 (2023) 57-69 https://doi.org/10.21608/IJMTI.2022.153909.1056

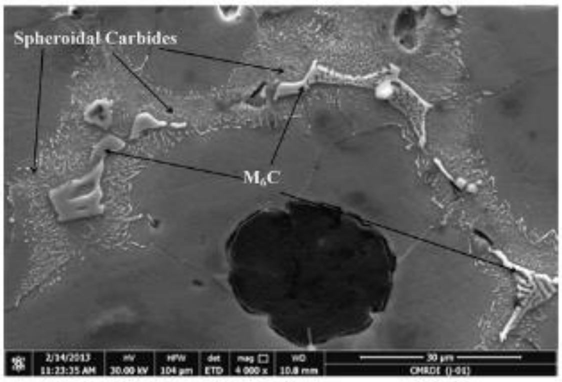

Fig. 7 Microstructure of SiMo ductile iron, showing graphite nodule in ferrite (white) with carbides of M_6C-type (M=Fe, Mo, Si), formed in the intercellular regions.

Due to the high cost of Ni-resist DI, interest in cast stainless steels increased which led to the development of ferritic and austenitic cast alloys. Where, these alloys are characterized by their high strength and resistance to corrosion at elevated temperatures resulting from their high Ni- and Cr-contents making them the appropriate choice for exhaust manifolds. Comparing to DI, stainless steel casting shows a lower castability due to lower carbon content which results in higher melting temperatures. Moreover, the absence of graphite in the matrix structure makes it more susceptible to solidification shrinkage. Both of the high melting temperature and expensive alloying elements significantly increase the cost of the parts compared to those produced from SiMo ductile iron.

Recently, automakers are trying to increase the efficiency of engines, i.e. reduce harmful gas emissions and fuel consumption as well as increase engine performance and comfort. In order to fulfill these demands, new fuel injection and exhaust gas treatment systems were developed, the turbocharger more used, as well as modern concepts of automobile production (downsizing, lightweight construction, etc.). The use of thin-walled SiMo in the exhaust manifold production will reduce the warm-up time which will speed up the extinguishing of the catalytic converter light and thus reduce emissions. However, the literature discussing the solidification behavior of thin wall casting sections made from Si-Mo irons are very rare. Therefore, the effect of alloying elements on carbide precipitation and hence on high-temperature properties needs to be better understood.

Table. 1 Maximum recommended temperatures for metals used in exhaust manifolds

Material	Maximum Temperature
Gray Iron	540 ˚C
Compacted Graphite Iron	650 ˚C
Ferritic Ductile Iron	760 ˚C
High Si-Mo Ductile Iron	870 ˚C
Ni-Resist Ductile Iron	925 ˚C
Ferritic Stainless Steel	955 ˚C
Austenitic Stainless Steel	1050 ˚C

5. Thin wall vermicular graphite cast iron (TWVGCI)

Vermicular graphite iron (VGI) is an engineering material that has attractive features makes it suitable to use in the automotive industry. High damping capacity and relatively low production cost of VGI are of high importance, particularly in thermally and mechanically simultaneously loaded thin-wall castings such as brake systems, heads and cylinder blocks [52, 53].

Thermophysical properties of TWVG castings are greatly affected by a graphite fraction, its morphology, metallic matrix and eutectic grains [54, 55]. A ferrite matrix has a higher thermal conductivity than a pearlitic one. VGI may have a complex microstructure, particularly in thin wall sections. This is owing to that the production of TWCI is not easy, because it is accompanied with a wide range of cooling rates at the beginning of graphite eutectic formation [56, 57].

The most important factors affecting the structure of VGCI castings are cooling rate, chemical composition, treatment during melting and heat treatment [58]. Cooling rate is affected by casting wall thickness, pouring temperature and the ability of the mold to absorb heat. As the cooling rates increase in TWVGCI castings, undercooling increases and graphite gradually turns into spheroidal, resulting in an increase in the number of nodules and a decrease in the proportion of vermicular graphite percent.

Furthermore, an increase in the cooling rate may leads to a risk of chill occurrence in cast iron. For this reason, a high degree of inoculation in TWDI or VGCI castings is necessary [58].

5.1. Mg treatment and anti-spheroidizing elements in TWVGCI

In the case of VGCI, increasing nucleation potential lowers the fraction of vermicular graphite and increases the spheroidal graphite ratio. Therefore, TWVCI is more difficult to produce than thick section [55]. The formation of vermicular graphite in thin section is not easy process with only a narrow margin of residual Mg. Higher residual Mg will raise the formation of graphite spheroids, whereas too lower residual Mg will promote the formation of flake graphite [59]. Therefore, a typical VGCI has a mixed structure with 5-30% of spheroidal graphite.

Literature [60], showed that even at low levels of magnesium, it is not possible to obtain acceptable VGCI with thicknesses of 4 mm due to high amount of graphite nodules. The treatment with anti-spheroidizing elements (Al, Bi, Ti, Zr, Sb) has much wider industrial application. Addition of titanium combined with Mg helps to extend the scope of action of magnesium for successful production of VGCI castings [58]. M. Górny and M. Kawalec [58] showed that, in thin-walled castings that solidified under high cooling rate with a high degree of inoculation, the addition of Ti helps in achieving homogeneous structure, carbide-free with a high VG fraction.

6. Some applications of thin wall cast iron (TWCI)

TWCI has a high potential for replacing various components of aluminum and steel in a lot of applications. ADI captured a wide area of applications in the vehicle sectors; some of the applications are crankshafts, gears, heavy truck, bus components, suspensions, transmissions, railway engineering and bracket trailer etc. The enhancement of TWCI technology permits the automakers to choose the most suitable material depending on cost/material properties considerations and not only on density.

The following parts were selected to clarify the employment of physical and mechanical properties of different types of cast iron. Figures (8-10) showed the forging control arms, cantilever and rotor castings made of aluminum alloy which were replaced by lighter and low- cost ductile iron castings. Figure 11 shows a wheel rim produced from Al-alloy (mass 5.30 kg) and its TWDI equivalent (mass of 5.23 kg). The microstructure of DI wheel rim showed that TWDI can be successfully produced without carbides which has good indicators of the properties.

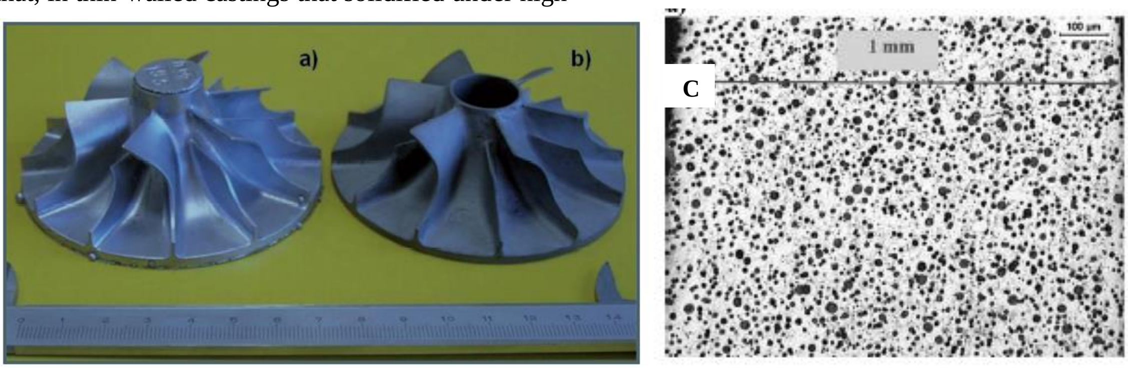

Fig. 8 Rotors: (a) aluminum alloy, (b) TWCI and (c) structure of rotor vane with 1.0 mm wall thickness [2].

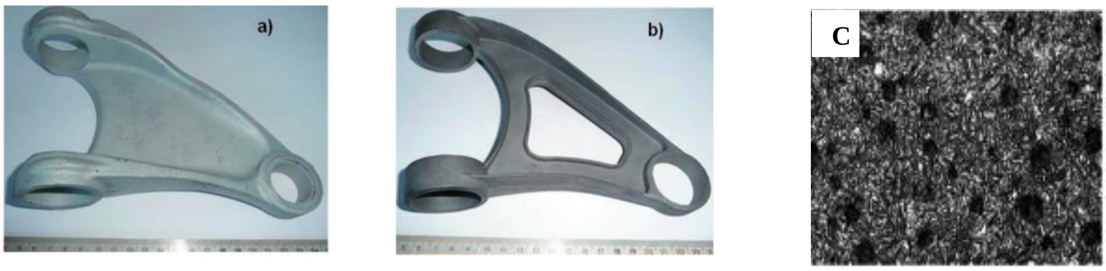

Fig. 9 Control arms made from: (a) forged Al- alloy (weight 585 g), (b) TWCI (weight 480 g) and (c) microstructure after heat treatment [2].

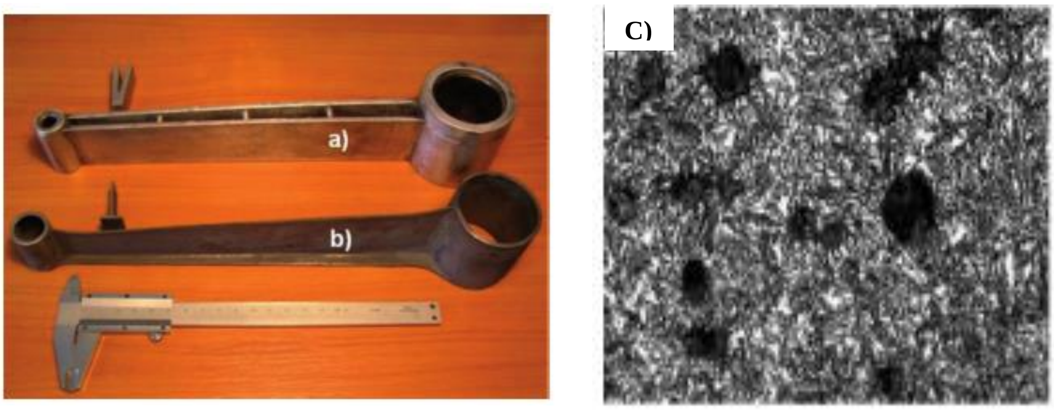

Fig. 10 Cantilevers made from: (a) Al- alloy (weight 580 g), (b) TWADI (weight 380g) and (c) microstructure after heat treatment [2].

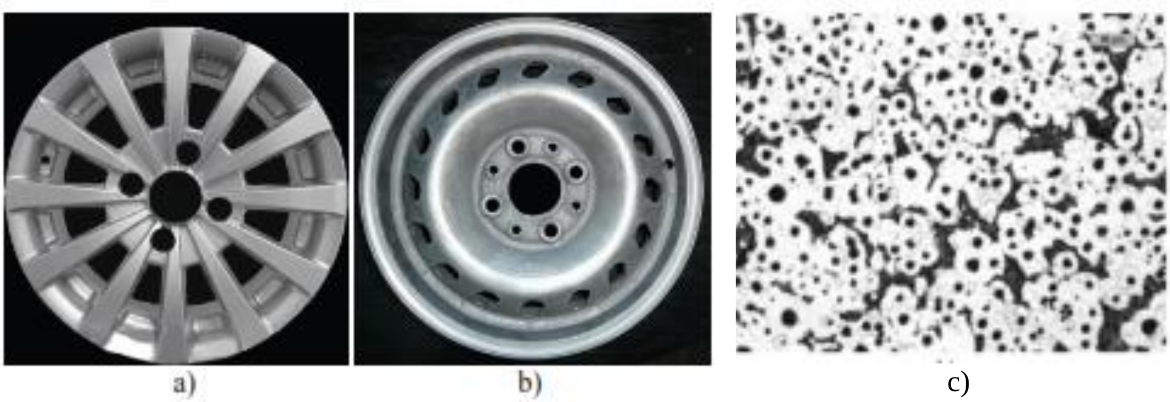

Fig. 11 Wheel rim produced from Al-Si7Mg alloy – a), wheel rim produced from DI – b) and microstructure of thin wall ductile iron in wheel rim (2mm) - c) [8].

In addition, the primary pump body is one of the applications of thin wall cast iron which is made of high Si gray iron with wall thicknesses as thin as 2.5 mm. Crankshafts are recently made of ADI replacing high- cost alloy and forged steel. Lightweight crankshaft designs can easily provide 15- 25% weight savings and aggressive designs can save 45-50% in weight by hollowing-out main and pin bearings and using ADI, Fig.12. A large number of brackets and mounts are made of TWDI and grey iron which have excellent vibration damping capabilities, while brackets and mounts made of low carbon steel are easily welded. Concerning to the use of thin wall SiMo ductile iron in high temperature applications, it is used widely to produce exhaust manifolds with wall thicknesses of 4.0 mm or less.

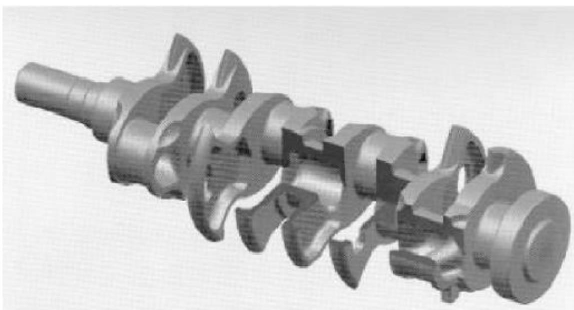

Fig. 12 Example of concept lightweight crankshaft [61].

7. Conclusions

This review article showed that thin wall cast iron (TWDI, TWADI, TW SiMo and TWVGI) castings have a high potential to replacing low density alloys (Al, Mg and composites) in varied applications. It is possible to obtain sound and carbide free thin wall cast iron castings through controlling different parameters such as molding materials, chemical composition, pouring temperature, types of inoculants and its amount as well as other foundry basic practices.

TWDI is an excellent material for austempering treatment as it does not need expensive alloying elements or long heat treatment time. The high nodule counts in TWDI and short diffusional lengths for segregation of alloying elements lead to lowered austempering time. The austempering treatment of TWDI improves the strength/weight ratio that approaches those of low-density alloys (aluminum, magnesium and composites) and makes it a convenient and economical alternative for use in automotive components. Furthermore, TWADI possesses strength, high wear resistance and damping capacity when compared with cast and forged steels.

TW SiMo ductile iron castings are economical material when used in high temperature applications between (650 -870°C), which makes it a popular choice for turbocharger housings and exhaust manifolds. To increase efficiency of the engines and consequently reduce the emission of harmful gases and fuel consumption, new trends of using TWCI made of SiMo ductile iron for the exhaust manifolds have been developed. However, the literature discussing the solidification behavior of thin wall casting sections made from Si-Mo irons are very rare. Therefore, the effect of alloying elements on carbide precipitation and hence on high temperature properties needs to be better understood.

VGCI has attractive properties that are used in the automotive industry. Good thermophysical properties, damping capacity, and relatively low production cost of VGCI are valuable, especially in thin section castings that are loaded at the same time such as brake systems, heads and cylinder blocks. As the cooling rates increase in TWVGCI castings, undercooling increases and graphite gradually becomes spheroidal resulting in an increase in the number of nodules and reduce vermicular graphite percent. TWVGI with a high vermicular graphite fraction and carbide-free structure can be obtained by controlling chemical composition and use of anti-sheroidizing elements such as Ti with low level of Mg.

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