ARTICLE IN PRESS

Materials Today: Proceedings xxx (xxxx) xxx

Contents lists available at ScienceDirect

Materials Today: Proceedings

journal homepage: www.elsevier.com/locate/matpr

The consequences of hot deformation and control cooling on the microstructure of medium carbon microalloyed steel – 38MnSiVS5 grade

Sujith Bobba [a,*], Bachina Harish Babu [b], Mukkollu Sambasiva Rao [c], Z. Leman [d]

[a] Department of Automobile Engineering, Vignan's Foundation for Science Technology & Research (VFSTR), Guntur, AP, India
[b] Department of Automobile Engineering, VNR Vignana Jyothi Institute of Engineering and Technology, Hyderabad, India
[c] Department of Foundary-Forge Technology, NIAMT (NIFFT), Ranchi, India
[d] Advanced Engineering Materials and Composites Research Centre (AEMC), Universiti Putra Malaysia, 43400 Serdang, Malaysia

ARTICLE INFO

Article history:
Available online xxxx

Keywords:
Micro-alloyed steels
38MnSiVS5
Hot deformation
Control cooling
Hydraulic press
Precipitation strengthening

ABSTRACT

Medium carbon micro-alloyed steels are mostly being utilized in the application where quenched and tempered steels are needed for cost-productive processing. However, the impact toughness of micro-alloyed steels is inferior to that of quenching & tempered steels, which resist their use in critical applications. Conventional techniques are used for hardness enhancement of micro-alloyed steels due to reduction in carbon percentage, the addition of relevant chemical constituent such as titanium to achieve the reduction in the amount of pearlite and controlling the microstructure during thermomechanical processing, subsequently after cooling and forging. In this research work, the effect of hot deformation and control cooling temperature on the microstructure of medium carbon micro-alloyed steel 38MnSiVS5 was studied. Different approaches were performed to improve the impact toughness and hardness and found out that forced air cooling of the micro-alloyed steel 38MnSiVS5 forgings resulted in the finest microstructure and exhibiting a higher hardness of 45.93 R_C.

Selection and peer-review under responsibility of the scientific committee of the International Conference on Materials Innovation and Sustainable Manufacturing.

1. Introduction

A significant amount of hot forged elements is manufactured using direct cooled micro-alloyed steels. The elements are mainly treated as a less cost which is unconventional to high alloyed quenched and tempered steels. Cost reduction can be ascribed for both in the reduction of cost in alloying additions and a substantial depletion of the post forging application. A typical application of micro-alloyed forging steels includes automotive components such as crankshafts, connecting rods, spindles, and wheel hubs.

Micro alloyed steels utilize small inclusion, frequently in the order of 0.1 wt% or less, alloying constituents like Niobium, Vanadium or Titanium to improve mechanical properties through grain size control and precipitation strengthening. In forging steels, micro alloying additions are commonly used to improve medium carbon weight percentage and bainitic steel or ferrite – pearlite is used to improve the fatigue resistance, tensile strength and common wear properties. Grain refinement of micro-alloyed steel is attained by both solute drag or precipitating micro-alloy carbides and nitrides out of the solution at higher temperatures to manage the austenite grain size and its morphology during refining. The precipitation strengthening of micro-alloyed steels can be significant, typically increasing strength by 50 to 200 MPa. This rise in the strength is accomplished by precipitating very low volume fractions of very fine (typically < 20 mm) incoherent precipitates. The forging industry association (FIA) [1] describes that forging procedure can reduce lump to lump difference in contrast with additional manufacturing procedures, yet FIA does not consider the various levels of dissimilarities for various forging procedures. There are countless potential which give rise to lump variation. For instance, Altan and Shirgaokar [2] found out sources such as forging procedure kind, machine parameters, strain amount, die contact time and specimen temperature. In all cases, the properties of these steels are controlled by the microstructure. Major

* Corresponding author.
E-mail address: sujith.bobba@mail.com (S. Bobba).

https://doi.org/10.1016/j.matpr.2023.04.290
2214-7853/
Selection and peer-review under responsibility of the scientific committee of the International Conference on Materials Innovation and Sustainable Manufacturing.

Please cite this article as: S. Bobba, B.H. Babu, M.S. Rao et al., The consequences of hot deformation and control cooling on the microstructure of medium carbon microalloyed steel – 38MnSiVS5 grade, Materials Today: Proceedings, https://doi.org/10.1016/j.matpr.2023.04.290

strengthening by solid solution strengthening is hardly practicable in steels of the type considered here so the desired results must be achieved by a combination of precipitation hardening and modification of the matrix structure [3]. An extreme case is found in the case of Ti steels when Ti is virtually insoluble at temperatures high enough for Titanium carbide to be soluble. Consequently, Ti forms, often in the liquid and uses up, thus TiC formed at lower temperatures is virtually free [4]. Precipitation in austenite reduces the potential for precipitation in ferrite and the resultant strengthening. However, careful attention to composition and rolling schedules can ensure an adequate degree of precipitation in ferrite [5]. Normally, the grain coarsening temperature rises with the total process but is less than the temperature needed for the preferred dissolution of the micro-alloy nitride or carbide existed. Therefore, steels including insoluble TiN coarsen at many elevated temperatures than steels including the more soluble VCN. These outcomes concur numerical with predictions of models of grain boundary restrained by precipitate molecules [6]. The Micro alloying element has the most profound effect on increasing recrystallization temperature. The elements precipitate are very effective for intermediate temperature for exploitation, for example, such as recrystallization temperature control [7]. Equbal et al. [8] differentiated the consequences of forging parameters on the mechanical properties of two categories of steel such as medium carbon steel and medium carbon steel micro-alloyed with a portion of vanadium. Babakhani et al. [9] found out that the inclusion of titanium had a considerable impact on grain refinement and therefore, had a positive outcome on the mechanical properties such as hardness, impact and toughness. Kaynar et al. [10] carried out comparative research on the consequences of after forging cooling grades on the microstructure and mechanical properties of two grades of forging steels that are medium carbon steel and medium carbon vanadium micro-alloyed steel, the outcome showed that the micro-alloyed steels had high strength, hardness and lower percentage elongation when compared to medium carbon steels for different cooling parameters due to a rise in vanadium percentage. A rise in the cooling rate can enhance the level of cooling and therefore improve the operating force of the stage transformation. Reduction in the pearlite transformation temperature reduces down to the spreading of carbon atoms and lessen the advancement rate of pearlite. Therefore, the fusion of hot deformation, promoting the cooling quantity and reducing the pearlite transformation temperature can successfully refine the pearlite inter lamellar position [11,12]. The purpose of the study is to experimentally examine the strain rate of micro-alloyed steel-38MnSiVS5 with the alloying elements such as vanadium (V) and nitrogen (N) and manganese (Mn) during the process of heat cycle during forging.

2. Experimental procedure

2.1. Sample preparation

Primarily from hot rolled, micro-alloyed steel nine samples were taken out with a diameter of 60 mm and length 90 mm and proceeded with 30% and 50% deformation of the samples. For the deformation first, the material dimension was estimated for forging. So, from nine samples, sixteen samples of diameter 40 mm and length 40 mm were machined. After theoretical calculation, the first proper dimension for forging of raw material was going through the turning & facing process by lathe machine. For turning & facing operation tool is made with silicon carbide and the specimen was cut into proper length with dimension of 40 mm by hand grinder cutting wheel machine. The specimens were polished as per standard metallographic procedures for optical microscopy examinations.

2.2. Material specification

To investigate the impact caused due to reheating tempered specimens with 60 mm and 40 mm in diameter and 90 mm and 40 mm in length were austenitized in the induction furnace for 6 min at 1100 and 1180 °C as shown in the Fig. 1.

Three cooling rates were employed in this investigation such as still air-cooling, forced air-cooling and water spray-cooling. To control the consequences of direct cooling amount following forging on the microstructure and mechanical properties of the billets, subsequently, after forging in at 1200 °C in the hydraulic press at a temperature range of 1100–1200 °C, the specimens were cooled in dissimilar amounts.

2.3. Forging and foundry

The real point to use forging is that it presses up to their utmost specification (maximum force, maximum sum of strokes per minute). Normally free forging operations uses calm force, throughout monitoring of hydraulic presśs life time period and machinery operations (see Table 1).

Forging was performed using hydraulic press which weighed about 150 tones and pneumatic hammer of 150 kg with overall 170 blows per minute. All forgings were done with a specimen geometry, having a diameter of 60 mm and length of 90 mm as shown in Fig. 2.

Radial deformation of 30% & 50% from prepared stock as shown in the Table 2 below, the desired shape of samples was cuboid and from rolled steel the dimensional stopper is prepared with the help of the lathe machine which are shown in Fig. 3.

After forging all deformed samples were cooled by the sand and forced air, which for control cooling process. After forging all the specimens were tested under hardness, impact and finally microstructure analysis was performed to check the structure distribution and effects after the tests.

Fig. 1. Induction furnace used for experimental tests.

Table 1
Chemical composition of the experimental steels (wt %).

Steel	C	Mn	Si	S	P	V	N
Micro alloyed –38MnSiVS5	0.41	1.22	0.2	0.01	0.017	0.084	0.0057

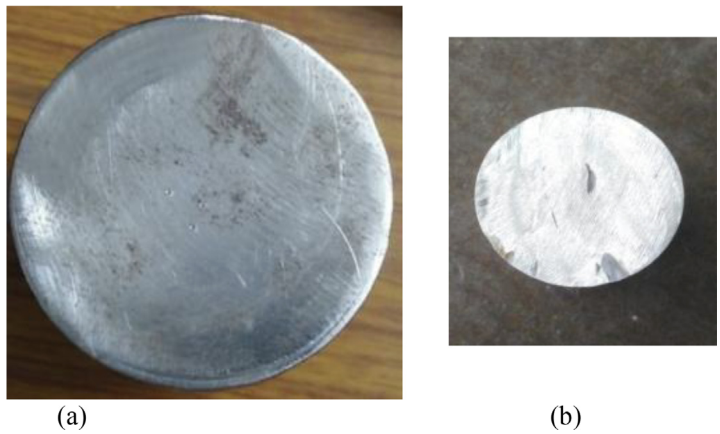

Fig. 2. (a) Diameter of 60 mm and length of 90 mm; (b) Diameter of 40 mm and length of 40 mm.

Table 2
Radial deformation of 30% & 50% of the samples used in the forging process.

S.No	Deformation(%)	A_i (mm^2)	A_f (mm^2)	A(mm)	approx. (mm)	L (mm)	Stopper height (mm)
1	30	1256.63	879.641	29.65	30	57	30
2	50	1256.63	628.315	25.06	25	80.04	25

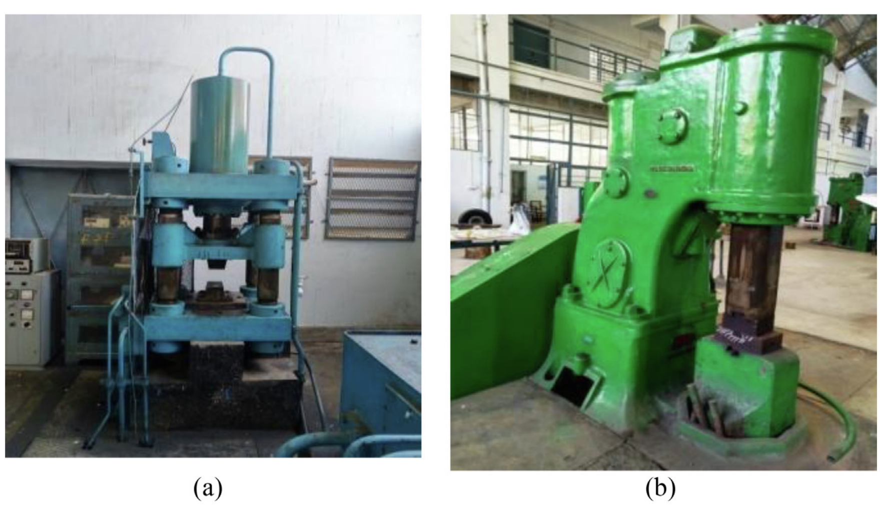

Fig. 3. (a) Hydraulic press; (b) Pneumatic Hammer (3cwt).

2.4. Hardness testing

For measuring hardness digital rockwell hardness testing machine with C scale was used as shown in Fig. 4. Firstly, for testing, it was required for surface cleaning by grinding machine. Then the specimen should place on the platform of the hardness testing machine. A minor load was applied on the surface by the diamond indenter then the load of 150 kg was applied to it. After 15–20 s to release the load measured the diameter of the indentation by the indenter on the sample surface. According to the diameter the hardness was calculated for each specimen.

2.5. Impact testing

Impact energy rate was calculated at room temperature by charpy impact testing machine as shown in Fig. 5 and by ASTM A 370–05 standards [8]. For the test the dimension of the specimens were 55 mm*10 mm*10 mm. Samples were prepared by hand grinding & vertical grinding machine. 50% deformed samples fulfilled the required length for this test. Notch (at an angle of 45° and of 2 mm depth) was made by notch cutting machine in each samples as shown in Fig. 6. Now samples were ready for impact test in charpy impact testing machine which was shown in the Fig. 5 below.

Fig. 4. Digital rockwell hardness testing machine.

2.6. SEM analysis

Samples for microstructure were taken from the steel forgings. These samples were polished on the emery paper grades 120, 220, 320, 400, 600, 1000, 1200, 1500 in such a way that the polished surface can face can be seen like mirror. Samples are observed on the optical microscope to see scratches on the surface. These scratches were removed by polishing on the cloth. The polished surfaces of samples were put in cotton to prevent any atmosphere attack. The samples were observed on optical microscope at x100, x50 magnification after etching and photographs were taken with the camera fitted to the optical microscope.

3. Results and discussion

As per the investigational details acquired following warm forging of medium carbon micro alloyed steel (38MnSiVS5) at various parameters the properties of materials have modified. The elongation, hardness, toughness, area of reduction and ultimate tensile strength of medium carbon micro alloyed steel – 38MnSiVS5 increased in the case of 50% deformation in pneumatic hammer (3cwt) with 60 min drenched time rather than 30% deformation with 60 min drenched time. Deformation influence on various mechanical properties of carbon micro alloyed steel (38MnSiVS5) using pneumatic hammer is shown in Table 3.

In the point of hydraulic press, it was observed that the hardness and toughness of medium carbon micro-alloyed steel (38MnSiVS5) increased by 30% deformation with 30 min drenched time whereas 50% deformation for 30 min drenched time. The ultimate tensile strength of medium carbon micro-alloyed steel – 38MnSiVS5 increased in the point under 30% deformation in the pneumatic hammer with 60 min drenched time than 50% deformation with 30 min drenched time. Deformation influence on various mechanical properties of carbon micro-alloyed steel (38MnSiVS5) using the hydraulic press is presented in Table 4.

The difference in the strength and toughness concerning the temperature rise is not notable and for the reduction, in the die wear, 1180 °C and 1100 °C were selected for forging. With this higher temperature, the resistance to fill the die is less and consequently after the process, the die.

Mechanical properties were decided by the tensile and impact tests which were performed at room temperature [14]. The ferrite and pearlite microstructure features and pearlite overall dimensions were obtained by using optical metallography. Fig. 7 shows

Fig. 6. V-Notch impact testing specimen.

Fig. 5. V-Notch cutting machine and charpy impact testing machine [13].

Table 3
Deformation (%) influence on various mechanical properties of carbon micro alloyed steel (38MnSiVS5) using Pneumatic hammer.

Temperature	Equipment Pneumatic Hammer Deformation (%)						
	30			50			
	Impact Testing (Joule)	Hardness (Rc scale)		Impact Testing (Joule)		Hardness (Rc scale)	
	Sand Forced and air Cooling	Sand Cooling	Forced air Cooling	Sand cooling	Forced air Cooling	Sand Cooling	Forced air Cooling
		30.7	–	–	64	–	34.63
1180	–						
			35.45	33	–	33.27	–
		41.5	–	64	–	38.83	–
1100		–	45.93	32	–	–	43.43

Table 4
Deformation (%) influence on various mechanical properties of carbon micro alloyed steel (38MnSiVS5) using Hydraulic press.

Temperature	Equipment Hydraulic Press Deformation (%)						
	30			50			
	Impact Testing (Joule)	Hardness (Rc scale)		Impact Testing (Joule)		Hardness (Rc scale)	
	Sand Forced and air cooling	Sand Cooling	Forced air Cooling	Sand cooling	Forced air Cooling	Sand Cooling	Forced air Cooling
		39.03	–	–	76	–	39.03
1180							
			36.7	93	–	36.13	–
		45.72	–	65	–	42.83	–
1100		–	43.9	88	–	–	40.37

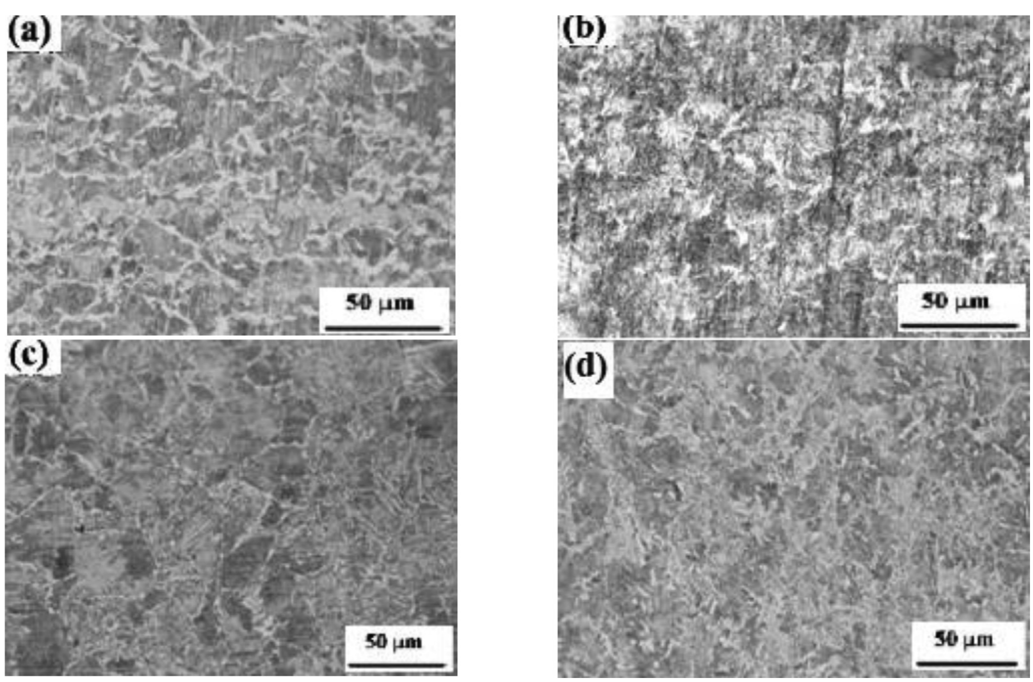

Fig. 7. (a) Pearlite – 70% and Ferrite – 30%; (b) Pearlite – 40% and Ferrite – 60%; (c) Pearlite – 25% and Ferrite – 75%; (d) Pearlite – 65% and Ferrite – 35%.

the microstructure of medium carbon micro alloyed steel – 38MnSiVS5 under as received and after subjecting to various post forging cooling conditions. as per result, we observed the maximum hardness is 45.93 R_c and minimum hardness is 30.7 R_c for 30% deformation in 70% Pearlite and 30% Ferrite, for 40% Pearlite and 60% Ferrite maximum impact is 93 but minimum hardness is 36.13 R_c, for 25% Pearlite and 75% Ferrite minimum impact was 32 but the hardness is 43.43 R_c for 65% Pearlite and 35% Ferrite.

So as per the SEM observations above in Fig. 7, the maximum toughness of any sample which have low hardness for the of grain formation with ferrite – pearlite mixture structure. Accordingly, the strength and hardness of the 38MnSiVS5 steel only vaguely decreases with the reduction in deformation temperature, while the elongation show a reverse trend. Besides, the 38MnSiVS5 steel is slightly unresponsive to the deformation temperature contrast with the cooling quantity and the transformation condition.

4. Conclusion

In view of the overhead discussion, the following conclusions are stated:

1. Air induction melting of mild steel scrap and addition of micro alloying elements in the furnace 3–5 min prior to pouring appears to produce the micro alloyed steel satisfactorily with around 80% recovery of micro alloying elements.
2. The soaking of the sample at 1180 °C and 1100 °C for 45 min prior to die forging gives desired results.
3. Forced air cooling of the micro alloyed steel forgings resulted in finest microstructure and exhibiting higher hardness 45.93 $R_{C.}$
4. Hardened and tempered steel is superior to micro alloyed steel in terms of mechanical properties. But hardening & tempering is costlier to air – cooling or sand cooling.
5. To reduce the manufacturing cost of automotive parts which we can still use micro alloyed steel, since its properties satisfying the industry standards.
6. Forging followed by air – cooling does not cause any harmful Sulphur segregation in micro alloyed steel. Forging of micro alloyed steel produces fibrous structure as desired.

CRediT authorship contribution statement

Sujith Bobba: Conceptualization, Software, Validation, Formal analysis, Investigation, Resources, Data curation, Writing – original draft, Project administration. **Bachina Harish Babu:** Methodology, Writing – original draft, Project administration, Supervision, Funding acquisition. **Mukkollu Sambasiva Rao:** Resources, Writing – original draft. **Z. Leman:** Resources, Writing – original draft.

Data availability

The data that has been used is confidential.

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: [Sujith Bobba reports was provided by Vignan's Foundation for Science Technology and Research. Sujith Bobba reports a relationship with Vignan's Foundation for Science Technology and Research that includes: employment.]

Acknowledgement

We would like to thank the Department of Automobile Engineering, Vignan University, Vadlamudi for having been a source of constant inspiration, precious guidance and generous assistance during the project work.

References

[1] R.S. Lee, J.L. Jou, Application of numerical simulation for wear analysis of warm forging die, J. Mater. Process. Technol. 140 (1–3) (2003) 43–48.
[2] T. Altan, M. Shirgaokar, Selection of forging equipment, Metalworking: Bulk Forming, ASM Handbook, vol. 14A, ASM International, Materials Park, OH, USA, 2015, pp. 36–46.
[3] S. Roy, A. Karmakar, S. Mukherjee, et al., Effect of starting microstructure on austenite grain sizes developed after reheating of HSLA steel, Mater. Sci. Technol. 30 (2014) 1142–1153.
[4] H. Peter, Microalloyed Forging Steels: A New Generation, Adv. Mater. A 134 (6) (1988) 23–31.
[5] Fundamentals and Applications of Microalloying Forging Steels, Conf. Proceedings, Edited by C. J. Van Tyne, G. Krauss and D. K. Matlock, The Minerals, Metals & Materials Society, Warrendale, Pennsylvania, (1996).
[6] J.K. Park, A.J. Ardell, Microstructures of the commercial 7075 Al alloy in the T651 and T7 tempers, Metall. Mater. Trans. A 14 (1983) 1957–1965.
[7] L. Zhang, T. Kannengiesser, Austenite grain growth and microstructure control in simulated heat affected zones of microalloyed HSLA steel, Mater. Sci. Eng. A 613 (2014) 326–335.
[8] M.I. Equbal, R.K. Ohdar, P. Talukdar, D. Mukerjee, Hot forging behaviour of medium carbon and microalloyed steel: a comparative study, Int. J. Microstruct. Mater. Propert. 12 (1/2) (2017) 1–11.
[9] A. Babakhani, A.R. Kiani-rashid, S.M.R. Ziaei, The microstructure and mechanical properties of hot forged vanadium microalloyed steel, Mater. Manuf. Process. 27 (2) (2012) 135–139.
[10] A. Kaynar, S. Gunduz, M. Turkmen, Investigation on the behaviour of medium carbon and vanadium microalloyed steels by hot forging test, Mater. Des. 51 (2013) 819–825.
[11] H.L. Wei, G.Q. Liu, X. Xiao, et al., Dynamic recrystallization behavior of a medium carbon vanadium microalloyed steel, Mater. Sci. Eng. A 573 (2013) 215–221.
[12] A. Bakkaloğlu, Effect of processing parameters on the microstructure and properties of an Nb microalloyed steel, Mater. Lett. 56 (2002) 263–272.
[13] ASTM A370–05, Standard Test Methods and Definitions for Mechanical Testing of Steel Products, ASTM International, West Conshohocken, PA, 2005.
[14] S. Bobba, S.R. Mukkollu, Z. Leman, H.B. Bachina, Experimental Investigation on the Effect Due to Mould Vibrations on Mechanical and Metallurgical Properties of Aluminum Alloy (A-1050), International Journal of Surface Engineering and Interdisciplinary Materials Science (IJSEIMS) 9 (1) (2021) 77–86, https://doi.org/10.4018/IJSEIMS.2021010105.