

Waza (Skilled Craftsmanship) that Produced “Honda Music”: Creation of RA272 Exhaust Pipe

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ABSTRACT

In the 1960s, when Honda won its first Formula 1 race, the Japanese automotive industry entered a new era. This study attempted to accurately reproduce and analyze the process of formation of the exhaust pipe of the winning RA272 engine, using the *waza* (skills) employed in its fashioning, which have been handed down by its makers. This analysis showed that the manual bending method, used to create the RA272 exhaust pipe, which was filled with sand and bent while being flame-heated, enabled the achievement of a continuous curve with a high bending limit, without the use of figures or molds, and was superior to the mechanical bending method of that time, from the standpoint of the degree of freedom of the layout, as well as that of speed of production. Study of the skills employed by sheet metal specialists at the moment of pipe bending has provided information on the bending temperature and point at which bending is initiated, which is important in elucidating the pipe production technique. The fact that the pipe displays lower residual stress from bending and that the microstructure of the material remains stable, even at exhaust temperatures of 700 °C to 900 °C, has also provided useful information on the pipe’s shape stability and mechanical strength.

1. Introduction

Participating in Formula 1 and other races is part of Honda’s culture, and Honda engineers have honed their *waza* (skills) under the limit conditions represented by racing. In 1965, in Honda’s first term of racing, the 1.5 L V12 RA272⁽¹⁾ (Fig. 1) won the Mexico Grand Prix. From the early days of the company’s involvement in racing, Honda’s prototype engineers have worked to create and supply engines and parts that meet the demands of racing vehicle design and satisfy the requirements of racing drivers. In order to keep the techniques that went into the creation of the RA272 alive, engineers are now attempting to accurately reproduce the vehicle using the *waza* that were originally employed in its creation. The design of the RA272 exhaust pipe to fit a predetermined layout earned the accolade “pipe art”⁽²⁾. This was a functional component that determined the power characteristic of the racing engine, and the term “Honda music” came to be applied to its particular dry, high-frequency exhaust note⁽³⁾.

Amid today’s quest for increasingly advanced manufacturing techniques using CAD, CAM, and CAE, it is not an easy issue to decide how to transmit and pass on *waza* and the value of those skills. In the process of

seeking a method of transmitting to coming generations the *waza* employed in the *tsukuri* (fashioning) of this exhaust pipe to which the appellations “art” and “music” had been applied, interest was generated in using contemporary measurement technologies to conduct a



Fig. 1 RA272

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Table 1 Manufacturing methods for Formula 1 vehicle exhaust pipes

	First term 1963-1968	Second term 1984-1992	Third term 1999-
Material	Steel pipe (STKM)	Stainless steel, inconel	Stainless steel, inconel
Manufacturing method	Manual bending	Mechanical bending, welding	Mechanical bending, welding, press forming
Engine type	V8, V12	V6, V10, V12	V10, V8
Photograph			

value analysis on the pipe. Introducing the *waza* that went into the creation of the “Honda music” that was part of this exhaust pipe is one method of attempting to ensure this *waza* is passed on. This paper attempts to introduce these *waza* to a large number of people and to pass them on to coming generations.

The term *waza* used in this paper refers to superior skills, unique to Japan, employed in the fashioning of objects. The tempering techniques used in the creation of Japanese swords, and the manufacture of the composite structure of the swords, which do not break despite their hardness, may be taken as an example. These were born from *waza* and a traditional mind-set that produced sword fabrication methods that have no equal elsewhere, resulting in a beauty that gives the swords a high value as art objects. The manual dexterity inherited from their ancestors and the traditional ethos of crafting displayed by the Japanese people have enabled *waza* to be passed down and to be continuously developed in unique ways, despite the nation’s lack of natural resources. These *waza* form the foundation of the Japanese automotive industry.

After confirming the validity of the instinctive decisions made on the basis of *waza* by the sheet metal specialist who recreated the RA272 exhaust pipe (Fig. 2), a value analysis was attempted by using a concrete evaluation method to compare the manual bending

techniques used with the mechanical bending method that was the rival method available at the time when the pipe was originally manufactured. This paper will introduce the *waza* employed in the fashioning of this exhaust pipe employed in Honda’s first term of involvement in racing, and present the findings resulting from this study.

2. The Exhaust Pipe

2.1. Change in Method of Manufacturing Exhaust Pipes for Racing Vehicles

Table 1⁽⁴⁾ shows the exhaust pipe materials and manufacturing methods, and the engine types employed, from Honda’s first to third terms of involvement in racing. During the first and second terms, the exhaust pipes were bent; in the third term there was a transition to press forming. This was because the quest for compactness made it necessary to employ a layout that exceeded the bending limit of the pipe, and formation using bending techniques thus became a challenge. A change in the materials used from steel to high-strength and high heat-resistance stainless steel and inconel was another reason for the change in manufacturing method. Today, also, modifications are made day by day, as engineers seek a compact structure that balances heat resistance with lower weight.

2.2. Exhaust Pipe Configuration

To enable the employment of a comparatively high-order exhaust pulsation⁽²⁾ in the high-speed, high-power (12 000 rpm, 230 ps) engine used in the 1965 RA272, the exhaust system employed four tail pipes, each of which was formed by three pipes converging into a single pipe (this configuration will be termed a “3-to-1 convergence” below) (Fig. 3). Table 2 shows the teams participating in races at the time and the engines that they used.

The exhaust pipe commenced from the flange connected to the engine exhaust head, and was made up

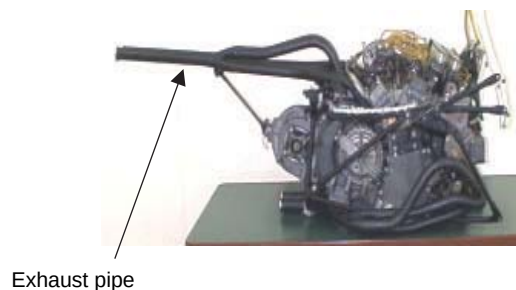


Fig. 2 RA272 engine and exhaust pipe

Table 2 Team and engine type

Team	Ferrari	BRM	Honda
Engine type	Dino 158 V8 1498 cc 210 ps 11000 rpm	B.R.M. 56 V8 1498 cc 220 ps 11500 rpm	RA 272 V12 1500 cc 230 ps 12000 rpm

of primary, collector, and tail pipes (Fig. 4). The system featured the greatest number of pipes of the systems used by any of the racing teams, but also employed the most compact layout. To minimize exhaust interference as much as possible, 12 pipes of equal length were employed, producing a 3-to-1 convergence that was easily mounted in the vehicle. Arranged compactly around the engine, the primary pipes were 12 pipes of different shapes, but of identical length, in a twining layout, leading to the application of the term “pipe art.”

2.3. Reproduction of the Exhaust Pipe

This section will discuss the main points that had to be observed in the reproduction of the exhaust pipe. As Fig. 5 shows, the mouth of the pipe that is connected to the flange is expanded and connected to the primary pipe. To attempt to ensure that there is no unevenness, the external diameter of the pipe should be uniformly expanded from 32 to 35 mm.

Figure 6 shows the primary pipe, displaying a continuous curve without joins from the first bend to the

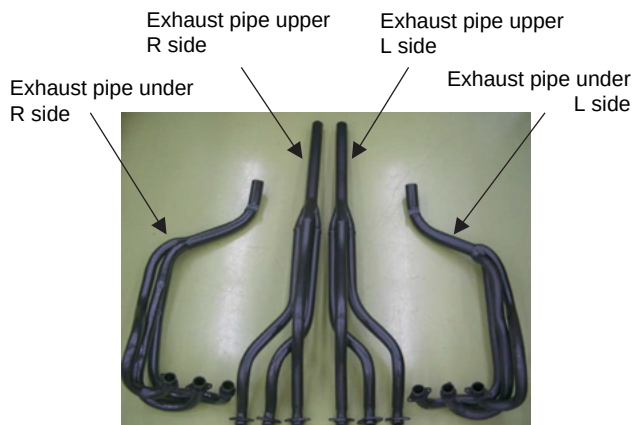


Fig. 3 RA272 exhaust pipe

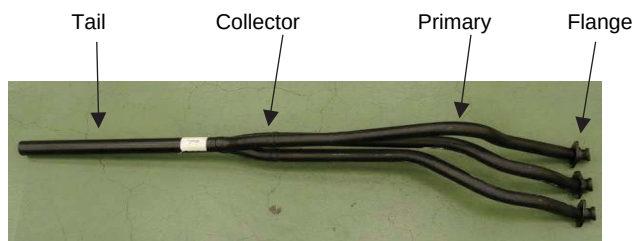


Fig. 4 Configuration of exhaust pipe

fourth bend. No diagrams or bending dies are used in the procedure. The pipe is filled with sand and bent, relying on feel, while being heated over a gas burner. This method of pipe manufacture uses a bending technique that necessitates highly developed *waza*.

To create a 3-to-1 convergence from the primary pipe, the pipe is cut in the shape shown in Fig. 7(a). The pipe is then clamped in a jig, and the sections are welded together while using a shield gas to attempt to prevent oxidation [Fig. 7(b)]. The optimum join is judged to have been achieved when scaly beads appear at the background of welding. Considerable experience in welding on ultra-thin sheets using tungsten inert gas welding is necessary. The welded areas of the 3-to-1 convergence are effective in controlling drag of exhaust gas, and thus become a concealed “tuning” mechanism, resulting in the pure high

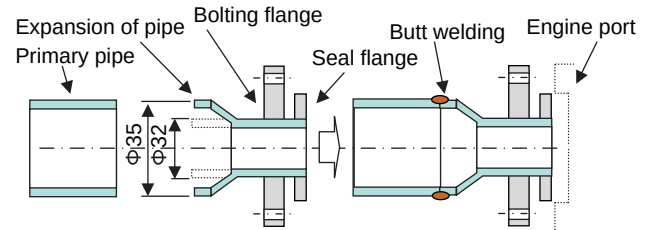


Fig. 5 Method of manufacture of flange

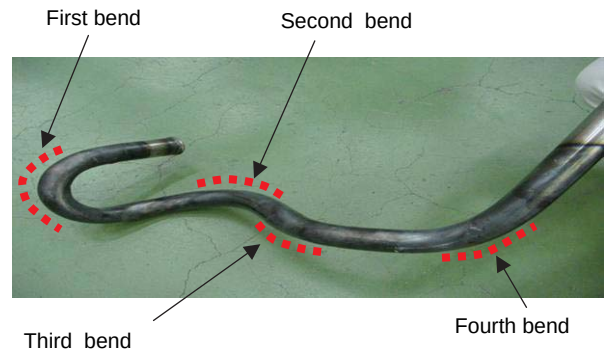


Fig. 6 Technique of bending primary pipe

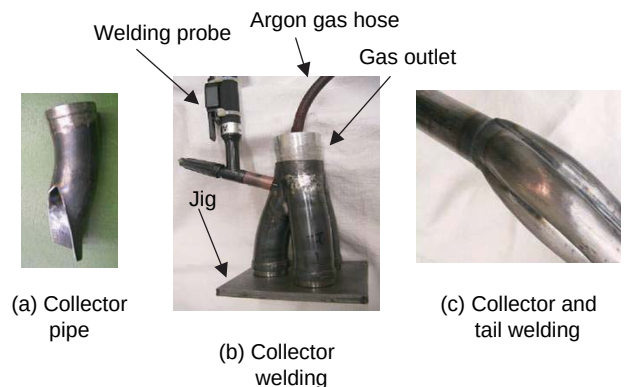


Fig. 7 Method of manufacture of collector

notes of “Honda music.” When the collector pipe in which the three pipes converge into one is joined with the tail pipe, as shown in Fig. 7(c), the pipe is completed. Having defined the various points to be observed in the reproduction of the “pipe art” of the RA272 exhaust pipe, as introduced in Section 2.2., the pipe has been recreated by Honda’s contemporary Racing Division using the *waza* of a sheet metal specialist.

3. The Waza of the Sheet Metal Specialist

Bending a pipe in the conventional manner results in wrinkles of the type shown in Fig. 8. In order to investigate the *waza* involved in producing the continuous curve in the primary pipe discussed in Section 2.3, the project studied the instinctive decisions of a sheet metal specialist, to whom the techniques of fabrication employed in the period of original manufacture of the pipe had been passed down (Fig. 9).

3.1. The Moment of Bending

The sheet metal specialist indicated that while watching the burnt color of the surface of the pipe, he would judge the moment to bend the pipe (Fig. 10) as the moment when his hands gripping the pipe felt that the pipe had lost rigidity. The project therefore examined the burnt color watched for by the sheet metal specialist and the moment of bending.

Figure 11(a)-(d) shows the results of measurements of the temperature of the pipe during flame heating, at the moment of bending, immediately after bending, and



Fig. 8 Conventional bending



Fig. 9 Sheet metal specialist

following natural cooling. The results indicated that the burnt color watched for by the sheet metal specialist occurred at around 820 °C. The bending operation commenced when the 820 °C area had expanded and covered approximately one-third of the surface of the pipe. At this point in time, the pipe lost its feeling of rigidity, and the sheet metal specialist judged that the moment was right for bending. Up to this point, it had been conjectured that the magnitude of the angle of bending was adjusted with a focus on the outside of the leading edge of the bend, where the material was stretched to the greatest degree. However, as the arrow in Fig. 11(c) shows, the section of the pipe with the highest surface temperature becomes the point of commencement of bending, and a bending radius is formed. The magnitude of the bending angle is adjusted by increasing or reducing the area at the bending temperature, centering on the point of origin of bending.

3.2. Correction of Bending

Immediately after the pipe is bent, flat sections are bent back a little against the direction of the original bending to bring them closer to a perfect circle. If this process leaves wrinkles on the pipe, the sheet metal specialist stops the flame and immediately flattens out the wrinkles using an iron hammer (Fig. 12).

A comparison of the external appearance and cross-section of a pipe before and after hammering is shown in



Fig. 10 Manual bending by specialist

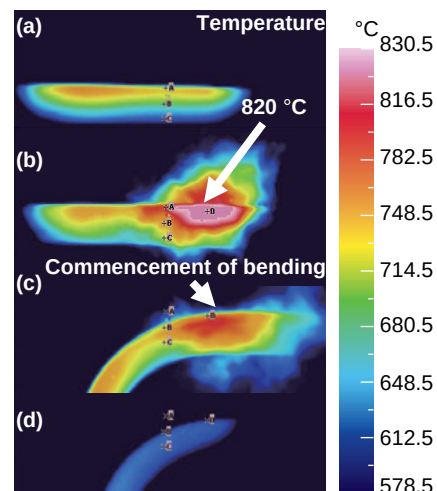


Fig. 11 Results of temperature measurement

Fig. 13. After hammering, the wrinkles have disappeared, and there are no flat areas. Following this, even if wrinkles occur in the radius section at the bending limit, hammering maintains a uniform pipe diameter, and the bend is connected to the next bend, completing the continuous curve of the primary pipe. This *waza* is a technique offering a higher degree of freedom in curvature, enabling a pipe to be bent with no joins to fit a tight layout. The origin of the primary pipe that played “Honda music” was the refined *waza* of the sheet metal specialist, using a hammer to flatten out any wrinkles.

3.3. Speed of Production

In the second term of Honda involvement in racing, mechanical bending was employed, and the materials were changed to high heat-resistance stainless steel and inconel. These methods were responses to the use of two racing teams and involvement in an increased number of races.



Fig. 12 Correction with hammer

However, due to the limitations of the bending machine and the bending limit of the pipe, a continuous bending could not be achieved, and this meant that pipes of different bending radii had to be connected, necessitating increased expense for benders and bending dies and resulting in increased production times.

The main reason for the use of manual bending during

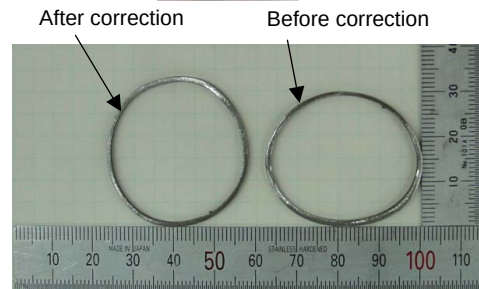
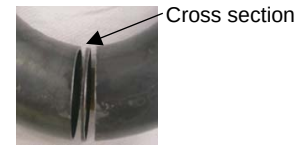


Fig. 13 Comparison of correction with hammer

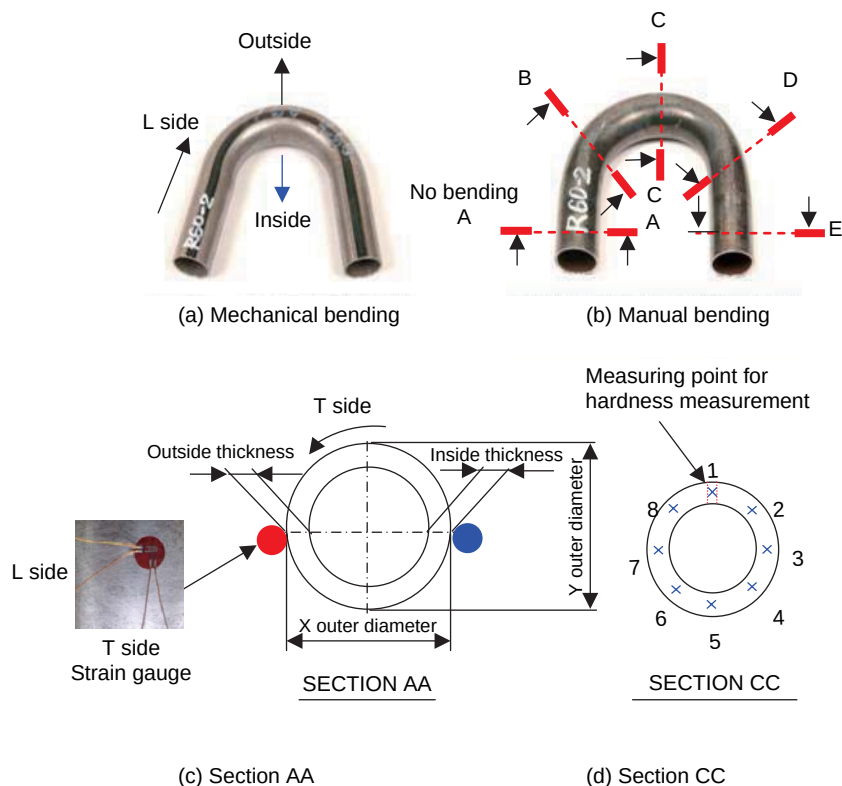


Fig. 14 Comparison of mechanical and manual bending

Table 3 Rate of change table of outer diameter and thickness

	Mechanical bending					Manual bending				
	Form	X outer diameter	Y outer diameter	Outside thickness	Inside thickness	Form	X outer diameter	Y outer diameter	Outside thickness	Inside thickness
Section A		34.14 mm	34.14 mm	2.21 mm	2.13 mm		33.49 mm	34.16 mm	2.10 mm	2.19 mm
B		-4.3 %	0 %	-23.5 %	23.0 %		-3.3 %	-1.0 %	-16.2 %	13.2 %
C		-6.2 %	-0.2 %	-18.6 %	22.1 %		-9.0 %	-1.2 %	-17.1 %	14.2 %
D		-5.0 %	-0.7 %	-22.6 %	23.5 %		-5.5 %	-0.1 %	-15.2 %	13.2 %

the first term of Honda racing involvement can be conjectured to be the fact that it enabled exhaust pipes with complex continuous curves to be manufactured in a very short period (within a single day) without the use of diagrams or bending dies.

From the qualifying sessions to the final race, races are completed within two or three days. Assuming that exhaust pipes could be manufactured at the race track, if a heat source was available and it was only a matter of producing two or three pipes, manual bending would enable production in time for the test laps. Exploiting the speed of this *waza*, the race teams of the first term of Honda racing chose a method of fashioning that enabled production right up to the moment of the final race.

4. Special Characteristics of the Manually Bent Exhaust Pipe

Section 3.3. above indicated that manual bending was superior to mechanical bending from the perspective of the manufacturing speed of the exhaust pipe. This section will present the results of a comparison of the quality and the performance of pipes manufactured using manual and mechanical bending techniques.

4.1. Change in External Diameter and Thickness

The effectiveness of the two bending techniques in the manufacture of a 180° U-shaped test piece with a radius of 60 mm was compared using 2.3 mm thick STKM with an external diameter of 34 mm [Fig. 14(a), (b)]. Due to the structure of the machine and the position of the bending mandrel, the shape of the test piece manufactured using the bending machine was slightly open, while manual bending enabled the achievement of a complete 180° curve.

The external diameter of the test pieces was measured in two directions (X and Y), and their thickness was measured at the inner and outer surfaces of the bend [Fig. 14(c)]. Table 3 shows the rate of thickness change of cross-sections B, C, and D against cross-section A, which had not undergone bending. In terms of change in external diameter, little difference can be observed between mechanical and manual bending, with reductions in diameter of only a few percent displayed by each. However, the rate of change of thickness at the inner and outer surfaces of the bend was lower in the case of manual bending at 31.3% against a maximum of 46.6% for that in mechanical bending. This demonstrates the superiority of manual bending in terms of bending marginal performance. In addition, the mechanically bent test piece displayed a higher rate of reduction of thickness at the outer surface of the bend in the cross-section from B to D, the origin and termination points of the bend, indicating that the highest degree of stretching of the material occurred at the outer surface of the bend.

4.2. Residual Stress caused by Bending

Residual stress was measured at the inner and outer surfaces of the test pieces using a strain gauge, as shown in the cross-section in Fig. 14(c). The results are shown in Fig. 15. As Fig. 15(a) shows, the test piece manufactured using mechanical bending displayed a higher level of strain due to residual stress on the inner surface at point B, close to the point of origin of the bend, and in addition, displayed higher strain than the test piece manufactured using manual bending at all measurement points. It can be predicted that the residual stress in the mechanically bent test piece would cause deformation as stress was released at the exhaust temperatures that occur during actual operation. By contrast, as shown in Fig.

15(b), manual bending is effective in minimizing variations in residual stress, resulting in a more stable shape.

4.3. Microstructure and Hardness

Measurements were taken at a cross-section of the leading edge of the bend in order to study the microstructure and hardness of the bent section [Fig. 14(d)]. The results of hardness measurements for the test pieces produced by mechanical and manual bending are shown in Fig. 16. Despite the fact that the hardness of the material declines because of heating during the manual bending process, the hardness is uniform and there is therefore minimal deformation of the toroidal shape.

In the mechanical bending process, the microstructure of the pipe becomes finer during work hardening, immediately following bending. Because of this, the product displays an excellent static strength characteristic from room temperature to around 700 °C, but the grain growth due to heating and deformation resulting from creep are both concerns. Grain growth and a coarsening of the microstructure due to flame heating can be observed in the case of the test piece manufactured using manual bending (Fig. 17). However, in tests from 700 °C to 900 °C, the predicted increase in exhaust temperature, the test piece produced using manual bending did not display the changes displayed by the mechanically bent test piece, indicating that its mechanical strength would remain stable under actual operating conditions.

5. Conclusion

The study discussed in this paper accurately reproduced the method of manufacture of the RA272 exhaust pipe, and compared the results with the results achieved using the mechanical bending method that was also available at the time of the original manufacture of

the exhaust pipe. The study produced the following conclusions:

- (1) The moment for bending the pipe in the manual bending process was reached when the temperature of the surface of the pipe was around 820 °C, and the magnitude of the bending angle was adjusted by increasing or decreasing the area of the pipe at this bending temperature, centering on the point of origin of the bend.
- (2) While mechanical bending was unable to produce a continuous bending and necessitated the use of benders and bending dies, manual bending enabled a pipe to be manufactured in a short period (within a day) without the use of diagrams or bending dies.
- (3) The maximum rate of change in the thickness of the inner and outer surfaces of the bend of a manually bent test piece was 31.3%, against 46.6% for a mechanically bent test piece, demonstrating the superiority of manual bending in terms of bending marginal performance.
- (4) The manually bent pipe displayed minimal residual

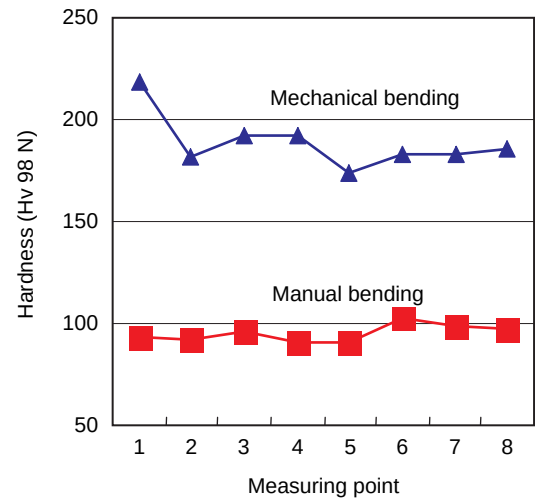
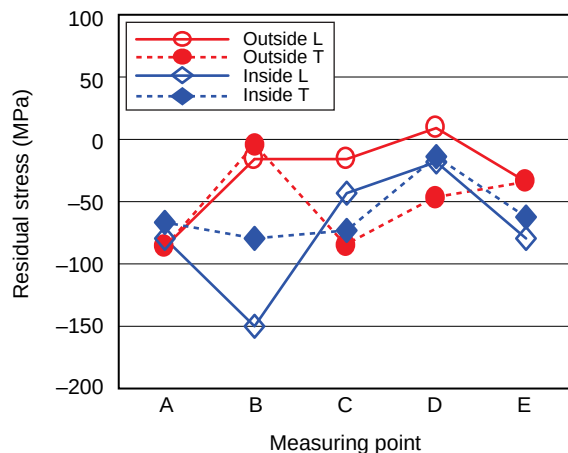
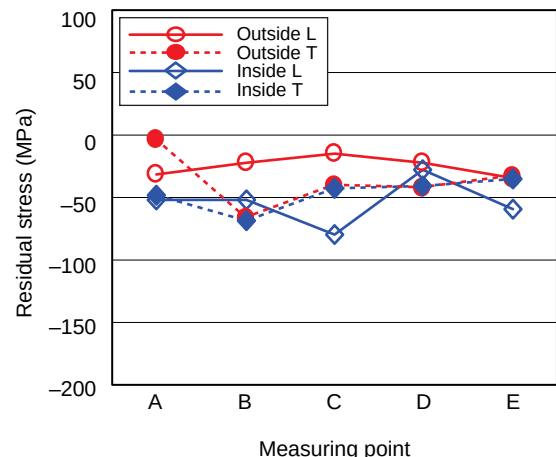


Fig. 16 Results of hardness measurements



(a) Mechanical bending



(b) Manual bending

Fig. 15 Results of residual stress measurements

6. Afterword

The study discussed here emerged from an interest in investigating “pipe art” and “Honda music” that was generated by the process of seeking a method of passing on *waza* to coming generations. The results achieved by the study indicated that the RA272 exhaust pipe displayed a higher level of performance than had at first been conjectured. The *waza* employed to reproduce the RA272 exhaust pipe as it was originally manufactured have been passed down by involvement in racing, and their considerable value, as indicated in this paper, is still an aspect of the manufacture of certain prototype production technology. The scientific measurements and analyses employed in this study have clarified the value of these *waza*. They have demonstrated that the methods used to fashion engine components represented an important element in Honda’s first race victory achieved in the Mexico Grand Prix. In addition, they have provided hints as to how to attempt to ensure that these *waza* are passed on from this point.

Honda’s early racing teams used their *waza* to create the world’s most sophisticated parts, competed in races and won, and in doing so passed on a dream to later generations. The purpose of this paper has been fulfilled if it has succeeded in introducing some part of those historical *waza*.

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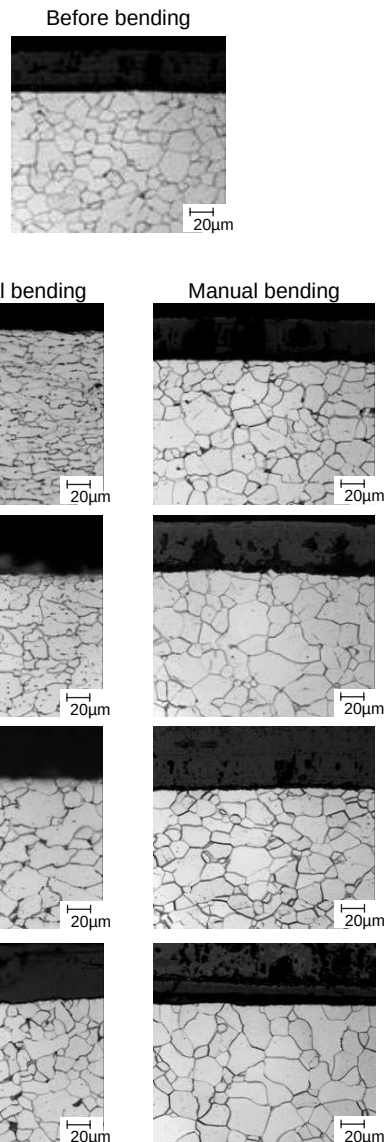


Fig. 17 Microstructure from normal temperature to 900 °C

stress. In addition, despite a decline in hardness, hardness was uniform, and there was minimal change in the toroidal shape. In tests simulating the increase in exhaust temperature, the microstructure of a test piece manufactured using manual bending did not display the magnitude of change of that of a mechanically bent test piece, indicating that its mechanical strength would be stable under actual operating conditions.

The *waza* that produced the RA272 exhaust pipe increased the degree of freedom of the layout, and was able to respond immediately to race requirements. The exhaust pipe also demonstrated its superiority in the fact that it displayed minimal residual stress, and would maintain its stability of shape and mechanical strength at exhaust temperatures.