Technical Paper

Development of Chlorine-free Hose for Construction Machinery to Raise Recyclability Rate

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To achieve Komatsu's target recyclability rate of 99.5 ± 0.5% for its construction machinery, high-pressure hoses with crimped metal fittings that are widely used on these machines needed to be made chlorine-free. As the outermost rubber sheath of the high-pressure hoses contains chlorine, they are unable to be heat recycled because incineration could release dioxin, and instead needed to be buried underground. On the other hand, the high-pressure hoses with crimped metal fittings account for about 0.5 to 1.0% of a construction machine on which they are used in terms of weight, which is not a negligible proportion.

Against this background, the authors, jointly with hose manufacturers, developed a chlorine-free hose with durability equal to or higher than chlorine rubber hose using a blended rubber material. Through subsequent material testing and durability assessment on actual machines, this recyclable chlorine-free hose was proved to have more durability than the conventional hoses. The conventional hoses were fully replaced with the chlorine-free hoses from the production in June 2012 and, as a result, the target recyclability rate of 99.5 ± 0.5% was achieved.

Key Words: *Construction Machinery, Material, Environment, Chlorine-free Hose, Chlorine Rubber, Recyclability Rate, High-pressure Hose with Crimped Metal Fittings, Dioxin*

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1. Purpose

The Japan Construction Equipment Manufacturers Association established the "Criteria for Assessment of Recyclable of Component of Construction Equipment and Actions for Improvement of Recycling[1)]," and set out its target of technically-feasible recyclability rate (in weight) of construction equipment as 97% or more[2)]. Komatsu has been striving to achieve the even higher recyclability rate of 99.5 ± 0.5%.

To achieve this target, it is essential to make rubber hoses with crimped metal fittings (**Fig. 1.1**) recyclable, which are currently buried underground for disposal.

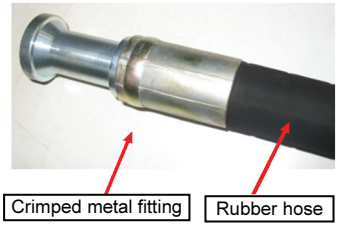

Fig. 1.1 High-pressure Rubber Hose with Crimped Metal Fittings

The Association proposes the following recycling methods for rubber hoses with crimped metal fittings: (1) making the crimped metal fitting detachable from the rubber hose and (2) use of chlorine-free rubber[1)].

The chlorine rubber can release dioxins as they are incinerated. Released amounts of dioxins can be reduced by incinerating chlorine rubber at high temperature, which however then releases chlorine gas, posing technical issues of how to treat the gas and prevent the incinerator from corroding. Due to these problems, rubber hoses have been buried underground without recycling their steel wire or crimped metal fittings.

Against this backdrop, Komatsu's project to develop a chlorine-free hose was started when the Materials Technical Center was established. Since then, quality verification and testing on actual machines have been carried out for about seven years. As a result, a chlorine-free hose was proved to have durability equal to or higher than the current chlorine rubber hose and the mass production of the chlorine-free hose started.

With the introduction of the chlorine-free hose, which can be recycled using the same process as that for steel radial tires, Komatsu's target of construction machinery recyclability rate of 99.5 ± 0.5% has been achieved.

2. Background for the Development of Non-chlorine Hose

2.1 Required quality of rubber hose with crimped metal fittings

Construction machinery such as excavators, bulldozers and wheel loaders use high-pressure hydraulic fluid as the power transmission medium and, for that reason, they are equipped with many high-pressure rubber hoses with crimped metal fittings. The reason of using such rubber hoses are that it enhances serviceability by easy removal and installation, and that the hoses can be used in areas where machine components are subjected to tight bend, long-stroke retraction and extension, and strong twisting force, to where the steel pipes cannot be used.

High-pressure rubber hoses with crimped metal fittings used in the harsh working environment of construction machinery must be durable enough to withstand abrasive soil, sand and rocks and millions of extension/retraction cycles and, for safety, have sealing performance sufficient to contain high-pressure fluid (e.g. 34.5 MPa) without any leakage. Furthermore, hydraulic hoses with crimped metal fittings must be made more reliable to meet the growing demand for higher operating pressure and larger cross sections, as the operation hours of the machines are becoming longer and the machine sizes are becoming larger.

2.2 Weight percentage of chlorine-free hose with crimped metal fittings

High-pressure rubber hoses are fortified with layers of steel wires to withstand millions of extension/retraction cycles. As a result, the weight of high-pressure hydraulic rubber hoses reaches 0.5 to 1.0% of the total weight of the machine on which they are used as shown in **Fig. 2.1**.

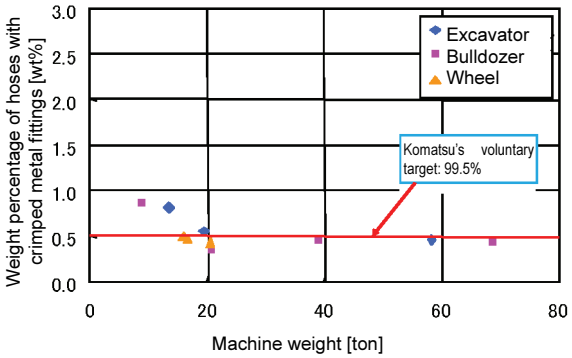

Fig. 2.1 Weight Percentage of Hoses with Crimped Metal Fittings in Total Machine Weight

These high-pressure rubber hoses have a weather- and heat-resistant rubber sheath as shown in **Fig. 2.2**, and the conventional hoses use chlorine rubber to that rubber sheath, which makes them unrecyclable by incineration or other means. They must be buried underground for disposal.

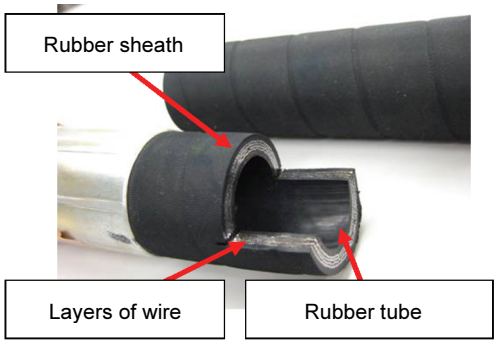

Fig. 2.2 Cross Section of Hose with Crimped Metal Fittings

Against this background, there has been a strong need for recyclable and durable chlorine-free hoses. Komatsu therefore started the project to develop a heat-, cold- and weather-resistant and strong chlorine-free hose using blended special rubber.

2.3 Why is chlorine rubber unrecyclable?

As the chlorine rubber is incinerated, it can release dioxins shown in **Fig. 2.3**. In an experiment conducted at a specialized research institute, chlorine hose rubber was incinerated in a sealed test tube at 600 to 800°C and the

generated gas and incineration residue were measured for dioxins. **Fig. 2.4** shows the total toxicity equivalence quantity (pg-TEQ/g) for the amount of dioxins generated, which was obtained by multiplying the measured amount of each generated material by its toxicity (equivalence factor).

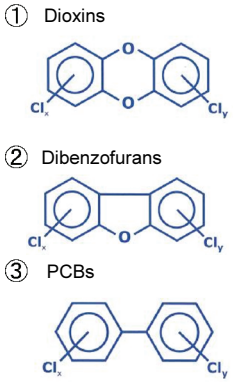

Fig. 2.3 Chemical Structures of Dioxins

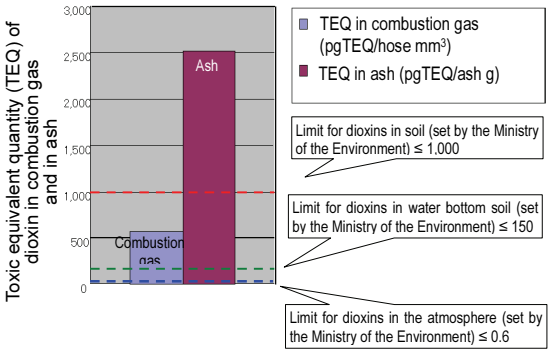

Fig. 2.4 Comparison of the Amount of Dioxins Released during Combustion of Chlorine Rubber (at 700°C)

The test tube experiment showed that the chlorine rubber can release levels of dioxins exceeding the limits of Ministry of Environment (MOE) in combustion gas and ash when incinerated at 700°C whereas the chlorine-free hose rubber material releases no dioxins at all when incinerated in the same condition.

The experiment also showed that the amount of dioxins released from the chlorine rubber decreased substantially when it was incinerated at 800°C or higher temperatures. However, such high incineration temperatures cannot be achieved or guaranteed at the existing incinerators. This means that, to make high-pressure rubber hoses with crimped metal fittings recyclable, it is essential to use chlorine-free alternatives to eliminate the possibility of dioxins above the MOE limits being released during incineration.

3. Development of the Chlorine-free Hose

3.1 Technical hurdles

To develop a chlorine-free hose, the following technical hurdles must be cleared.

- The chlorine-free hose must be as resistant to harsh environment (oil, heat and cold) as chlorine rubber hoses.
- The chlorine-free hose must be as durable (resistant to heat aging and weather) as chlorine rubber.

Fig. 3.1 Rubber Sheath Needs to be Chlorine-free

Chlorine rubber used in rubber sheath, shown in **Fig. 3.1**, has well-balanced physical properties required of high-pressure rubber hoses. It was a challenge to substitute chlorine-free rubber material for the chlorine rubber. In addition, considering that Komatsu machines used in emerging markets work longer hours than before, as mentioned earlier, anything that would undermine quality were not acceptable.

The biggest concern about chlorine-free hoses is resistance to oil. High-pressure hoses are often routed near the moving parts. Oil and grease on the sliding parts can drip onto the hoses, permeate through them to degrade the sheath, which may cause cracks.

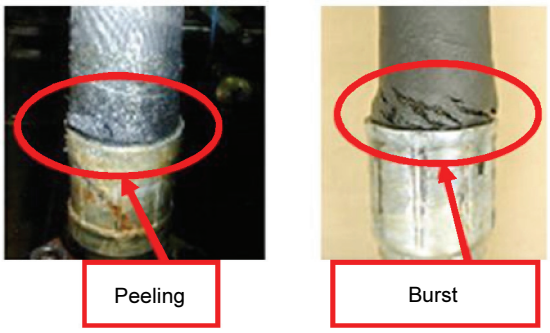

Fig. 3.2 Examples of High-pressure Hydraulic Hose Failures

Testing of hose unit with insufficient oil resistance revealed that cracks would develop on the hose surface as shown in **Fig. 3.2** and eventually the hose would burst or leak from the metal fitting crimped portion would occur under high pressure.

Komatsu has been evaluated many types of chlorine-free hoses for approximately seven years towards the development of a practical chlorine-free hose.

On the other hand, resistance to low temperature is another requirement for hoses as construction machines also work in extremely cold regions. The resistance to oil and the resistance to low temperature, however, are in a trade-off condition. Improvement in resistance to oil degrades the resistance to cold, and vice versa. (**Fig. 3.3**)

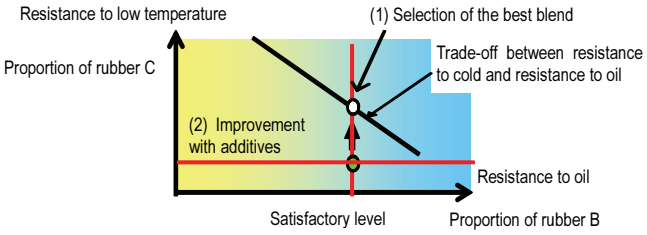

Fig. 3.3 Blending Rubbers for both Resistance to Oil and Low Temperature

In addition, to achieve full conversion to chlorine-free hoses, it was essential to prevent a substantial change in physical properties between the conventional hoses and new developed hoses and minimize cost increases.

To meet all of the requirements mentioned above, two or more rubber materials were blended at the optimum proportions and low temperature resistance was improved with additives, as shown in **Fig. 3.3** and **Fig. 3.4**, to obtain a rubber sheath with desired physical properties.

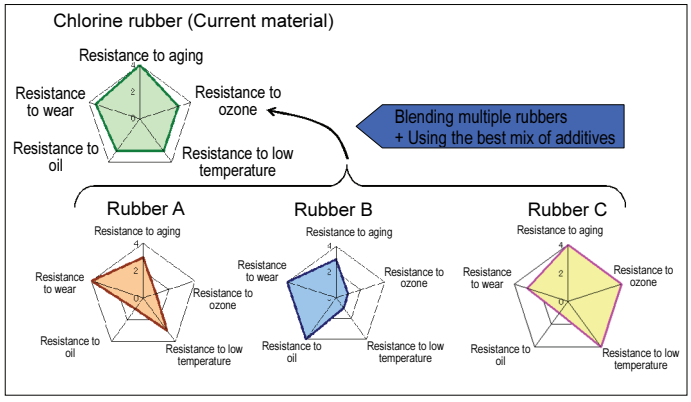

Fig. 3.4 Physical Property Balance for Most Common Rubbers

3.2 Heat life of the chlorine-free hose

The heat life of the chlorine-free rubber was estimated in a heat aging test. Normally, thermal degradation of rubber materials can be estimated using Arrhenius plots as shown in **Fig. 3.5**.

The plots indicate that the thermal deterioration of rubber progresses more at higher temperatures and at longer heating time. In this estimation, rubber was regarded as having reached the end of its life when its elongation had dropped by 50%.

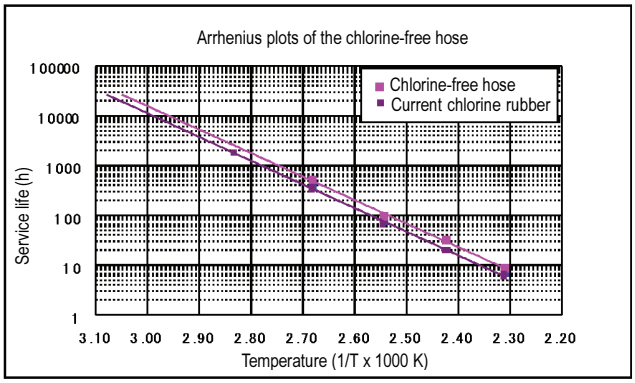

Fig. 3.5 Aging Resistance of the Chlorine-free Hose

The estimation exercise confirmed that the chlorine-free rubber material for the hose is equal to or better than the chlorine rubber of the current hose in heat life.

3.3 Weather resistance of the chlorine-free hose

The weather resistance of the chlorine-free hose was evaluated in (1) dynamic ozone degradability test and (2) exposure test.

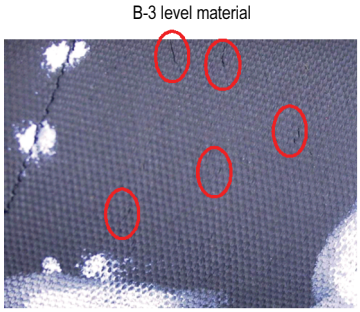

Fig. 3.6 Cracks on the Hose Surface that Emerged in Outdoor Exposure Test

The typical ozone cracks that appear on the rubber surface due to ozone degradation are shown in **Fig. 3.6**. The result of comparative analysis of crack occurrence rates based on the dynamic ozone degradability test (**Fig. 3.7**) indicates that the chlorine-free hose is better able to suppress the ozone cracks than the current hose.

A year-long exposure test for weather resistance (**Fig. 3.8**) conducted on the Island of Okinoerabu, known for high average temperatures and long hours of sunshine, found that the chlorine-free hose has an equal or better weather resistance than the current hose.

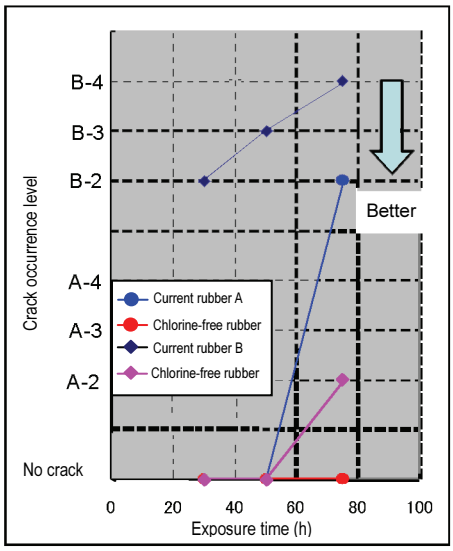

Fig. 3.7 Results of the Dynamic Ozone Test

Fig. 3.8 Year-long Exposure Test on Hoses

3.4 Low temperature resistance of the chlorine-free hose

The chlorine-free hose was evaluated on the low temperature elastic recovery test TR10. It measures the temperature at which a rubber strip stretched under a certain load retracts to a 10% stretch rate as it is warmed from -70°C. The TR10 was -30°C or below for both the current hose and the chlorine-free hose.

It was also found in a bend test on a hose that the threshold temperature was -50°C or lower, indicating that the hose can be used in extremely low temperature regions.

4. Test Performance of the Hose Assembly

4.1 Initial pressure test

Following the completion of durability test on the rubber material, tests were conducted on the hose assembly. In an initial pressure test which evaluated the pressure at which the crimped hose fitting came off the rubber tube in a burst (the relevant ISO standards require a safety rate at least four times the rated pressure), it was found that the hose assembly not only met the ISO requirement but, through optimization of the crimping structure, also had an equal or higher breakdown pressure than the current hose as shown in **Fig. 4.1**.

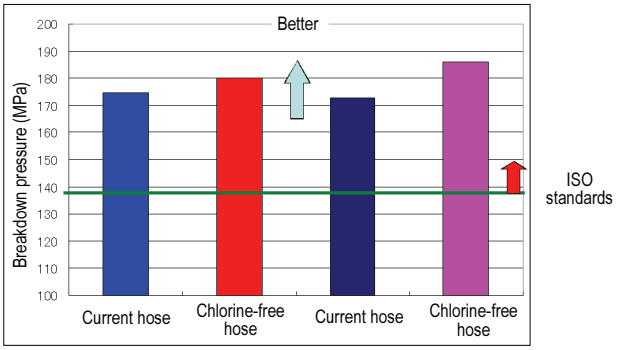

Fig. 4.1 Difference in Initial Breakdown Pressure

4.2 Impulse test on the hose

To test its durability, the hose was subjected to thermal load and pressure variation.

Fig. 4.2 Durability Evaluation under Heat and Pressure

Considering possible variation in production quality, the hose was evaluated at the upper and lower limits of the optimum crimping conditions.

The impulse test, conducted with the hose immersed in oil, found no drop in burst pressure at all pressures and hose sizes, raising no concern about the hose's performance and durability including oil resistance.

4.3 Durability test with the hose mounted on prototype machines

All types of hoses (5 pressure ratings and 8 end fitting sizes), which had passed the heat and weather resistance evaluations described earlier, were installed to the prototype machines for evaluation on actual machines.

Pressure	Size	Model A	Model B	Model C	Model D	Model E	Model F	Model G	Model H	Model I
4.5 MPa	02	●	●	●	●		●	●	●	
	03	●	●	●	●		●	●	●	
4.5MPa	02	●	●	●	●	●	●	●	●	
	03	●	●	●	●		●	●	●	
	04	●	●	●			●	●	●	
	05	●	●	●	●		●	●	●	
	06	●	●	●	●		●	●	●	
	10	●	●	●	●	●	●	●	●	●
	12	●	●		●	●			●	
	14	●	●	●	●		●	●	●	●
	20					●				●
17MPa	02			●	●	●	●	●		
	03			●	●		●	●		
	04			●			●	●		
	05					●	●	●		●
	06	●		●	●	●	●	●		●
	10			●	●		●	●		●
	12					●	●	●		●
	14									●
	20									
20.5MPa	02					●				
	03					●				●
	04					●				●
	05			●	●	●	●	●		●
	06			●	●	●				●
	10									
	12									
	14									
	20									
27.5MPa	02			●		●	●	●		●
	03					●				●
	04			●	●	●				
	05			●		●	●	●		●
	06	●		●	●		●	●		
	10	●	●	●	●		●	●	●	●
	12	●	●						●	●
	14		●						●	
	20									
34.5MPa	02	●	●	●	●	●	●	●	●	
	03					●				
	04	●								
	05					●				
	06	●	●	●		●	●	●		●
	10	●	●	●	●	●	●	●	●	●
	12				●		●	●		●
	14									
	20									

Fig. 4.3 Hose Types Installed to Each Prototype Machines

All the variations of the chlorine-free hoses were mounted to the prototype machines. Minimum operating hours for evaluation were 1000 hours while major models were operated over 4000 hours. All the hoses were collected for visual and property examination. No significant deterioration in durability was found on these hoses. After long hours of operation, the hoses maintained the breakdown pressure almost the same as the new hoses and showed no problem.

4.4 Applications of the chlorine-free hose

After the chlorine-free hose was tested on actual machines, it was decided that in actual applications the hose would be used only as hydraulic fluid hoses, not as fuel hoses. This is of safety reason. While the biodiesel fuel (BDF) is expected to be introduced rapidly among construction machines, the chlorine-free hose rubber may likely deteriorate at different rates with different types of BDF. The chlorine-free hose will still need to be fully tested with all types of BDF on actual machines to validate its quality.

4.5 Mass production of the chlorine-free hose

After completing the actual tests using the prototype machines successfully, Komatsu registered the accepted chlorine-free hoses with various pressure ratings and end fitting sizes, excluding the fuel system applications, in the Komatsu Engineering Standards, and started their mass production. Using these chlorine-free hoses, Komatsu's voluntary environmental target of 99.5 ± 0.5% recyclability rate for its construction machines was achieved.

4.6 Efforts to increase the actual recycling rate

The definition and calculation of recyclability rate was established by the Japan Construction Equipment Manufacturers Association. These criteria roughly correspond to those of ISO 16714 (which uses the term "recoverability"). Both standards treat both the material recycle and the thermal recycle as recyclability. While the recyclability rate is a design calculation, what is equally important is actual recycling rate.

To increase actual recycling rates, it is essential to identify and sort chlorine-free hoses from chlorine rubber hoses in waste processing processes. For that purpose, as a first step, "CLF" is added to the product name and is stamped on the hose surface. (The second step: The marking will be improved to meet ISO 1043-1 standards.)

While rubber hoses do not have sufficient thermal capacities as a heat source, they can be used as an ingredient of cement. Rubber hoses can also be used as a reducing agent at iron furnaces, like rubber shoes, as a material recycle[3].

As described above, the introduction of chlorine-free hoses not only helps increase the recyclability rate but also is expected to contribute greatly to the improvement of actual recycling rates.

5. Conclusion

(1) Heat impulse test conducted on chlorine-free, high-pressure rubber hoses with crimped metal fittings found that these hoses have the same or higher durability than the current hoses in all sizes and at all pressure ratings that are used on excavators, bulldozers, wheel loaders and other construction machines.

(2) Chlorine-free hoses that had passed the above-mentioned heat and weather resistance tests were then mounted on prototype machines for three years for evaluation. The chlorine-free hose was released for practical applications after confirming that there are no degradation or other quality issues.

(3) The introduction of the chlorine-free hose for practical applications

With the mass production of the chlorine-free hose, the high-pressure hose with crimped metal fittings can now be recycled using the same method that is used for steel radial tires, improving the recyclability rate for these

hoses that account for 0.5 to 1.0% or more in weight of the construction machines on which they are used. As a result, Komatsu's voluntary environmental target of 99.5 ± 0.5% recyclability rate for its construction machines was achieved.

(4) Efforts to increase the actual recycling rate of the chlorine-free hose

To identify and sort chlorine-free hoses from chlorine rubber hoses, currently "CLF" is marked on the surface of the chlorine-free hoses as a first step. While the recyclability rate is a design calculation, what is equally important is actual recycling rate. The chlorine-free hose can be used not only as an ingredient of cement, but also as a reducing agent at iron furnaces, like rubber shoes, as a material recycle.

References

1) Criteria for Assessment of Recyclable of Component of Construction Equipment and Actions for Improvement of Recycling, Japan Construction Equipment Manufacturers Association (March 2008)
2) Recycling Promotion Plan for End of Life Construction Equipment, Japan Construction Equipment Manufacturers Association (July 2001)
3) Kazuyuki Nabeoka, Trends in Efforts to Reduce Substances of Concern used on Construction Machines, Construction Mechanization (Journal of Japan Construction Mechanization Association), (December 2011), pp.61-65
4) Yoichiro Hanada et al., The Development of Chlorine-free Hose for Construction Machinery to Improve Recyclability, Collection of Papers Presented at the 42nd Symposium on Reliability and Maintainability, (2012), pp.371-376

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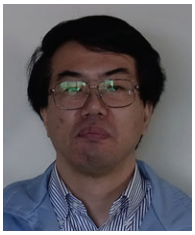

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[A few words from writers]

High-pressure hoses with crimped metal fittings are used for a wide range of applications. It was not easy to change the material of such hoses while maintaining the performance. Nonetheless, the project was successfully completed with cooperation from all those across Komatsu, especially from the Procurement Division, the Production Division, the Quality Assurance Division and our suppliers, with the Materials Technical Center (currently under the Research Division) and the Development Division playing the leading role in the project. We would like to take this opportunity to thank all those for their dedication who had participated in the project. We will keep up our effort to reduce the materials of concern to the environment. This report is based on the corresponding presentation made at the 42nd Symposium on Reliability and Maintainability[4].