PP-RCT: A NEW MATERIAL CLASS FOR PLUMBING AND HEATING APPLICATIONS

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ABSTRACT
Plastics materials are rapidly replacing copper pipes and fittings in domestic plumbing and heating systems throughout the world. Over the last 20 years pressure pipe systems made from Polypropylene Random Copolymers (PP-R) have been widely adopted by the plumbing and heating industry in numerous countries around the world. However, while over that period system components have been progressively improved, the basic plastic used has remained essentially the same.

This is now set to change with the recently developed new generation of materials using a special "β-nucleation" process, namely PP-RCT. This process enhances the crystalline structure which enables pipes produced from the material to operate at higher stresses at elevated temperatures. Pressure tests on pipes manufactured from PP-RCT materials demonstrate a 50 year strength at 70ºC (158°F) of 5 MPa (725 psi), compared to the 3.2 MPa (464 psi) for standard PP-R materials. Offering more than a 50% improvement in long-term strength, PP-RCT enables designers to select thinner walled pipes and in some situations also smaller diameter pipes can be used. This results in higher pipe hydraulic capacity or the possibility to apply higher pressure than with standard PP-R

The paper describes the characteristics and properties of the material and illustrates the benefits it offers to the complete value chain.

1. MATERIAL CHARACTERISTICS OF PP-RCT

1.1 CRYSTAL STRUCTURE AND MORPHOLOGY

PP-RCT is a polypropylene-random-copolymer which possesses a unique morphology. In comparison to standard PP-R, which displays only the monoclinic form (α-form), the crystal structure of PP-RCT consists to a high degree of the hexagonal form (β-form) and to some minor extent of the monoclinic form. The presence of both crystal forms can easily be seen in the melting behaviour of PP-RCT as it shows two distinct peaks in the DSC plot (Figure 1) of the second heating curve.

The formation of the hexagonal crystal structure is developed using a special β-nucleation technology. The addition of a nucleating agent provides crystallisation nuclei that dramatically increase the growth rate of β-crystallites and thus favour the formation of a stable hexagonal crystal structure. The special β-nucleating agent not only promotes the development of the hexagonal structure but also leads to a fine crystal structure and a homogeneous crystallite size distribution (Figure 2), attributes, that positively affect the mechanical characteristics of a material.

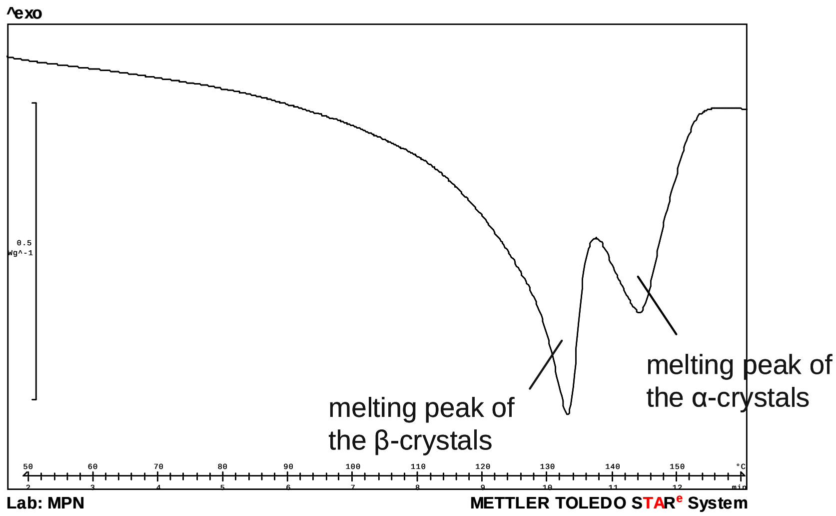

Figure 1: Typical DSC plot of the second heating curve of PP-RCT (measured on Beta-PPR RA7050)

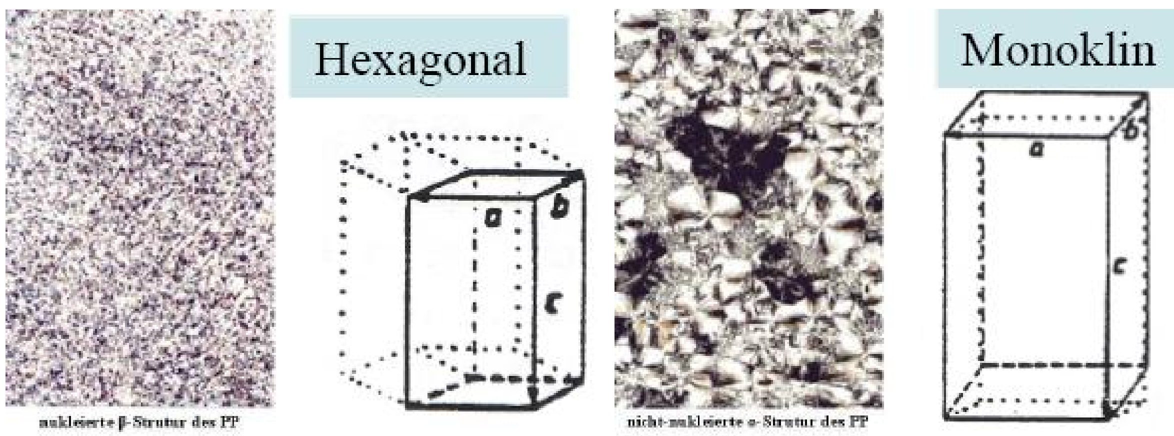

Figure 2: The β-nucleation results in very small crystallites of predominantly the hexagonal structure and an even crystallite size distribution (left) in comparison to the monoclinic structure of non-nucleated PP (right)

Further information about the morphology and structure of β-nucleated polypropylene can be found in the references [1], [2], [3], [4] and [5].

1.2 HYDROSTATIC PRESSURE PERFORMANCE OF PP-RCT

One of the most important properties of a polymer material used for hot and cold water pressure pipes is its resistance to internal pressure at different temperatures. A standardised method to evaluate this behaviour is described in ISO 9080 [6] and was also conducted on Beta-PPR RA7050, representing the new material class. This investigation was carried out at the accredited Swedish institute Bodycote Polymer AB and comprised the testing of more than 150 pipes at 5 different temperatures – with the highest test temperature of 110°C (230°F) – and testing times of more than one year. The results of the single failure points are depicted in Figure 3.

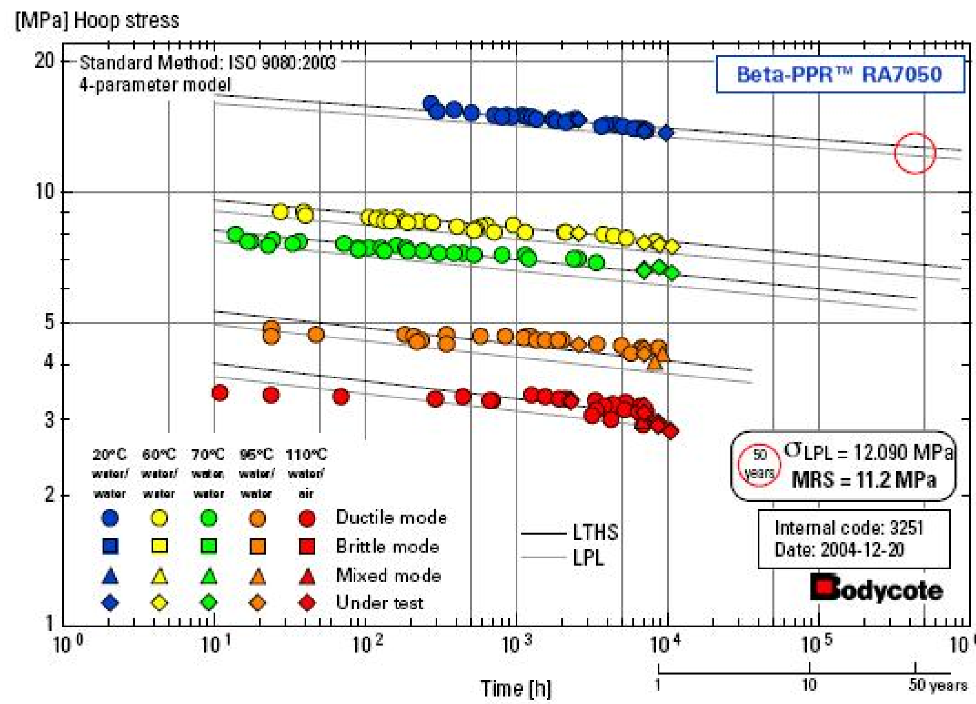

Figure 3: Graphical representation of the results of the hydrostatic pressure testing of the PP-RCT material according to ISO 9080

It is interesting to note, whilst at intermediate test times standard PP-R pipes show a "weeping" mode of failure, this is absent in PP-RCT pipes. Instead only ductile failures are observed up to one year of testing and this even at the highest test temperature of 110°C (230°F). Standard PP-R already shows brittle failure after around 1000 hours at this temperature. This demonstrates the excellent thermal stability of the new generation material.

Table I: Extrapolated strengths values

Temperature	Time [years]	σ_{LPL}	σ_{LTHS}
20°C (68°F)	50	12.1 MPa (1755 psi)	12.7 MPa (1841 psi)
20°C (68°F)	100	11.9 MPa (1725 psi)	12.5 MPa (1812 psi)
60°C (140°F)	100	6.23 MPa (903 psi)	6.64 MPa (963 psi)
70°C (158°F)	50	5.33 MPa (773 psi)	5.69 MPa (825 psi)
95°C (203°F)	4.17	3.63 MPa (526 psi)	3.89 MPa (564 psi)
110°C (230°F)	1.04	2.82 MPa (409 psi)	3.04 MPa (441 psi)

The individual failure points are then statistically evaluated and extrapolated following the rules of ISO 9080. The results of this extrapolation are summarised in Table I. It can be seen from the extrapolated data that the material has a MRS value of 11.2 MPa. As the MRS value only describes the performance at 20°C (68°F) and 50 years it is not that relevant for plumbing and heating applications. For these applications the performance at elevated temperatures is the crucial issue. The introduction of the universal function called CRS (θ;t) makes it possible to describe and characterise the performance of plastics materials for such operating conditions. The CRS (θ;t) is the Categorised Required Strength value of the σ_{LPL} determined and categorised for the selected temperatute (θ) and required service life (t) in accordance with ISO 9080. Hence, the CRS at 70°C (158°F) and 50 years is the important value for design purposes. The new generation material shows a value of 5.0 MPa compared to 3.2 MPa for standard PP-R.

Now, in order to define the minimum requirements for the hydrostatic pressure performance of the PP-RCT, reference curves were deduced from the assessment of the long-term behaviour of the Beta-PPR RA7050 according to ISO 9080. These reference curves form the basis for the pipe design and are described by the following equation:

$$\lg t = A + \frac{B}{T} * \lg s + \frac{C}{T} + D * \lg s \qquad (1)$$

with:

σ = circumferential stress (hoop stress) in MPa
T = temperature in K
t = time in hours
A = –119.546
B = –23738.797
C = 52176.696
D = 31.279

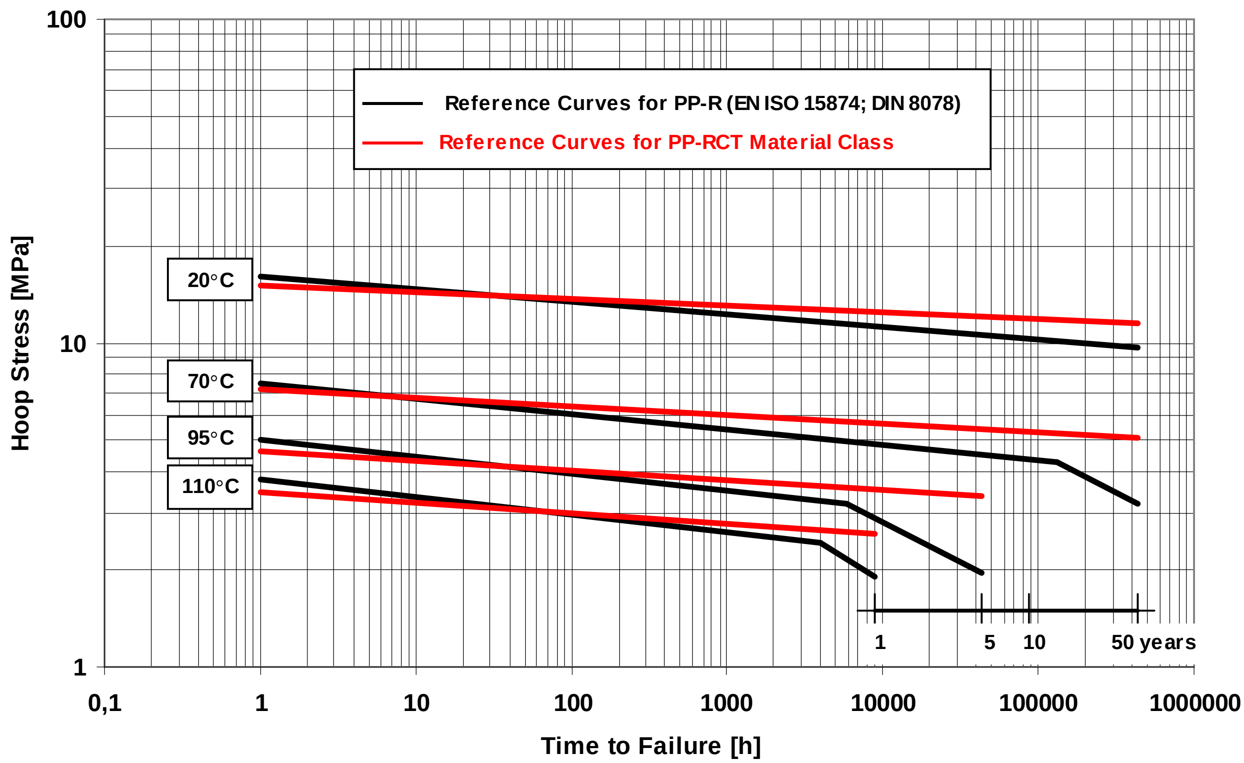

Figure 4: Comparison of the reference curves of PP-R and PP-RCT. The curves define the required hydrostatic pressure performance of the materials.

Equation (1) is valid for the temperature range of 10°C (50°F) to 110°C (230°F) and a graphical representation of the reference curves is given in Figure 4, which also includes a comparison to standard PP-R. This graph clearly illustrates the higher long-term strength of the PP-RCT compared to standard PP-R. A summary of the individual data is given in Table II. The improved long-term strength of the PP-RCT leads, of course, to a more economic set of dimensions of the pipe system for plumbing and heating applications (see Chapter 2).

Table II: Required long-term strength (Comparison of PP-RCT to PP-R)

Temperature	**Time [years]**	**Required long-term strength PP-R**	**Required long-term strength PP-RCT**
20°C (68°F)	50	9.7 MPa (1406 psi)	11.5 MPa (1667 psi)
60°C (140°F)	50	4.9 MPa (710 psi)	6.1 MPa (884 psi)
70°C (158°F)	50	3.2 MPa (464 psi)	5.1 MPa (739 psi)
95°C (203°F)	5	1.9 Mpa (275 psi)	3.3 MPa (478 psi)
110°C (230°F)	1	1.9 MPa (275 psi)	2.6 MPa (377 psi)

2. CLASS DESIGNATION AND SYSTEM DESIGN WITH PP-RCT

The designation PP-RCT was adopted following the guidelines given in ISO 1043-1 [7]. The symbols "R", "C" and "T" were chosen as they best describe the characteristics of this new class of polypropylene. A polypropylene-random-copolymer ("R") with a special crystalline structure ("C") (Chapter 1.1) which exhibits an improved pressure resistance especially at elevated temperatures ("T"), i.e. it shows a tougher behaviour (Chapter 1.2).

Table III: Classification of service conditions according to the product standards for plastics piping systems for hot and cold water installations

Application class	Design Temperature T_D °C	Time at T_D year	Maximum Design Temperature T_{max} °C	Time at T_{max} year	Malfunction Temperature T_{mal} °C	Time at T_{mal} h	Typical field of application
1	60	49	80	1	95	100	Hot water supply (60°C)
2	70	49	80	1	95	100	Hot water supply(70°C)
4	20 plus cumulative 40 plus cumulative 60	2,5 20 25	70	2,5	100	100	Underfloor heating and low temperature radiators
5	20 plus cumulative 60 plus cumulative 80	14 25 10	90	1	100	100	High temperature radiators

Product standards for plastics piping systems (e.g.: ISO 15874 [8] for polypropylene) are applied on an international basis for hot and cold water installations. These product standards specify the performance requirements for four different application classes which in turn define the operating conditions (Table III).

The first step to determine the required pipe dimension for a given application class is to calculate the design stress from the equation for the reference curves (e.g. Equation (1) for PP-RCT) using Miner's rule in accordance with ISO 13760 [9]. Account must be taken of the applicable class requirements and the service design coefficients (also known as safety factors). The design stresses for PP-RCT and PP-R are summarised in Table IV.

Table IV; Design stresses for PP-R and PP-RCT

Application class	**Design stress for PP-R**	**Design stress for PP-RCT**
1	3.09 MPa (448 psi)	3.63 MPa (526 psi)
2	2.13 MPa (309 psi)	3.40 MPa (493 psi)
4	3.30 MPa (478 psi)	3.67 MPa (532 psi)
5	1.90 MPa (275 psi)	2.92 MPa (423 psi)
20°C / 50 years	6.93 MPa (1005 psi)	8.24 MPa (1195 psi)

In a last step the required pipe series for a particular application class is calculated from the design stress and the operating pressure. The outcome of this calculation for operating pressures of 8 bar (116 psi) and 10 bar (145 psi) are presented in Table V.

Table V: Comparison of the required pipe series and SDR for PP-R and PP-RCT for the individual application classes

	Operating pressure 8 bar (116 psi)		**Operating pressure 10 bar (145 psi)**	
	PP-R	**PP-RCT**	**PP-R**	**PP-RCT**
Application class 1 60°C hot water supply	S 3.2 SDR 7.4	S 4 SDR 9	S 2.5 SDR 6	S 3.2 SDR 7.4
Application class 2 70°C hot water supply	S 2.5 SDR 6	S 4 SDR 9	S 2 SDR 5	S 3.2 SDR 7.4
Application class 4 Underfloor heating and low temperature radiators	S 3.2 SDR 7.4	S 4 SDR 9	S 3.2 SDR 7.4	S 3.2 SDR 7.4
Application class 5 High temperature radiators	S 2 SDR 5	S 3.2 SDR 7.4	————	S 2.5 SDR 6

From Table V it is clear that in most cases pipes made of PP-RCT with a thinner wall compared to standard PP-R can be utilized for the specific areas of application. This leads to a higher hydraulic capacity, which in turn results in substantial savings of material, labour and costs when designing the system.

Another way of looking at the performance of a plastics pipe is to consider the permissible operating pressure for a given pipe dimension at a specified temperature and service life. This approach is, for example, chosen in DIN 8077 [10], which shows tables for the permissible operating pressures for polypropylene pipes. A comparison of the permissible operating pressures (including a safety factor of 1.5) for pipes of different dimensions made of PP-R and PP-RCT is shown in Table VI. This again demonstrates the better performance of the new material class in that pipes made of PP-RCT can withstand much higher operating pressures than pipes of the same dimension made of PP-R.

Table VI: Permissible operating pressures in bar (including a safety factor of 1.5)

Temperature	**Operating Time [years]**	**S4 (SDR 9)**		**S 3.2 (SDR 7.4)**		**S 2.5 (SDR 6)**	
		PP-R	**PP-RCT**	**PP-R**	**PP-RCT**	**PP-R**	**PP-RCT**
20°C (68°F)	10	17.2	19.9	21.7	25.1	27.4	31.6
	25	16.6	19.6	21.0	24.6	26.4	31.0
	50	16.2	19.3	20.4	24.3	25.7	30.6
40°C (104°F)	10	12.3	14.7	15.5	18.6	19.6	23.4
	25	11.9	14.4	15.0	18.2	18.8	22.9
	50	11.5	14.2	14.5	17.9	18.3	22.6
60°C (140°F)	10	8.7	10.6	11.0	13.4	13.9	16.8
	25	8.4	10.4	10.5	13.1	13.3	16.5
	50	8.1	10.2	10.2	12.8	12.9	16.2
70°C (158°F)	10	7.3	8.9	9.2	11.2	11.6	14.1
	25	6.3	8.7	8.0	10.9	10.0	13.8
	50	5.3	8.5	6.7	10.7	8.5	13.5
80°C (176°F)	10	5.1	7.4	6.4	9.3	8.1	11.7
	25	4.1	7.2	5.1	9.1	6.5	11.4
95°C (203°F)	5	3.2	5.6	4.1	7.1	5.2	8.9

Therefore, the new material class PP-RCT offers two options to utilize its potential. Either, choose thinner pipe walls and take advantage of the higher hydraulic capacity or apply a higher pressure compared to pipes made of standard PP-R.

3. SYSTEM DESIGN

Today the most common pipe series for PP-R is the S 2.5 (SDR 6) with the 20 mm (¾ inch) pipe the smallest pipe diameter used. The hydraulic capacity of the 16 mm (½ inch) SDR 6 pipe is simply not sufficient to provide the required volume flow and operating pressures and is, therefore, hardly used at all.

However, the higher strength of the PP-RCT allows the use of SDR 7.4 pipes instead of SDR 6. As the thinner pipe walls result in a higher hydraulic capacity, a major part of the installation can be provided by16 mm (½ inch) pipes. Figure 5 illustrates the results of the calculation of required pipe dimensions and pipe lengths for two different projects; the large and complex ZVSHK certification model system and a residential building with eight apartments.

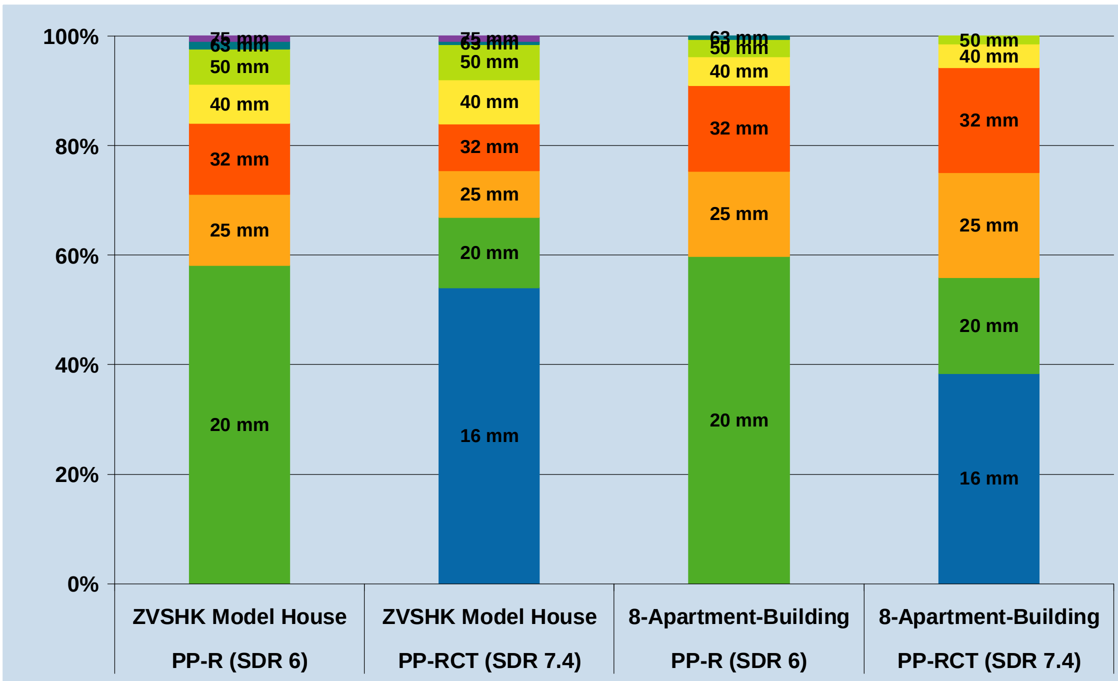

Figure 5: Comparison of the required dimensions and pipe lengths for the ZVSHK certification model system and an eight-apartment residential building.

The computation was carried out with the DVGW-certified calculation programme of the Dendrit Haustechnik Software GmbH, Germany. It is based on the requirements of the DIN 1988 [11] codes of practice for drinking water installations.

The design of an installation with the Dendrit calculation programme assures the optimum functionality of the water supply system. Over-dimensioning as well as unnecessary stagnation is avoided and each unit is supplied with a sufficient volume flow of water. Therefore, it is important that any system, from a residential house to an office complex of several storeys, should be calculated and not simply estimated using "rule of thumb".
In this way the benefits of the new PP-RCT material can be maximised. Moreover, the actual work of the installation becomes easier and faster through easier pipe cutting, lower space requirement for the installation, less insulation material needed and so on. Not least important, the substantially lower material usage provides an additional contribution to the conservation of resources supporting a sustainable environment. In the above examples you have material savings from the pipes of 29 % for the ZVSHK certification model system and 26 % for the eight-apartment residential building.

4. EASY TO INSTALL

Pipes and fittings made from the new material class PP-RCT are jointed with heated tool socket welding, in the same way as for standard PP-R. This jointing technology, proven over many years, produces a materially-bonded, secure and safe connection. The heated tool socket welding is a quick and easy process (Figure 6) and plumbers familiar with standard PP-R don’t need to learn a new technology or invest in new equipment.

The procedure including the individual welding parameters is fully described in DVS 2207 Part 11 [12].

Figure 6: The heated tool socket welding – a fast and simple procedure

5. CERTIFICATION AND STANDARDISATION OF PP-RCT PIPES AND FITTINGS

Testing and supervision programmes for a pressure pipe system made from the new PP-RCT have been developed by the SKZ (Süddeutsches Kunststoff-Zentrum). This guideline, HR3.34 [13], lays down the raw material requirements and defines the tests in order to obtain the SKZ quality mark for pipes and fittings (type testing, batch release testing and audit testing).

Furthermore, the German standards DIN 8077 [10] and DIN 8078 [14] covering pressure pipes made of PP are being revised to include the new material class PP-RCT. A draft of both standards had been issued and they have been published for public scrutiny. Another standard under revision to include the PP-RCT is the Austrian standard ÖNORM B5174 [15].

6. OUTLOOK AND CONCLUSIONS

Clearly the PP-RCT pipe systems offer a number of important benefits. This can be illustrated from an example in the Middle East, where it is common practice to install the water supply tank on the roof and use the force of gravity to distribute water around the building. Using thinner walled pipes made of PP-RCT material provides a better flow capacity to all tapping points around the building, which is greatly appreciated by the local plumbers and designers.

REFERENCES

1. A. Turner Jones, J.M. Aizlewood, D.R. Becket, *Crystalline Forms of Isotactic Polypropylene,* from the Imperial Chemical Industries Limited, Welwyn Garden City, Herts., England, 1963
2. P. Jacoby, B.H. Bersted, W.J. Kissel, C.E. Smith, *Studies on the β-Crystalline form of Isotactic Polypropylene*, Journal of Polymer Science: Part B: Polymer Physics, Vol. 24, 461-491, 1986
3. S.C. Tjong, J.S. Shen, R.K.Y. Li, *Mechanical Behavior of Injection Molded β-Crystalline Phase Polypropylene,* Polymer Engineering and Science, Vol. 36, No. 1, 1996
4. J. Varga, F. Schulek-Tóth, *Crystallisation, Melting and Spherulitic Structure of β-Nucleated Random Propylene Copolymers,* Journal of Thermal Analysis, Vol. 47, 941-955, 1996
5. *Polypropylene: Structure, Blends and Composites, Vol.1. Structure and Morphology,* Ed. J. Karger-Kocsis, Chapman and Hall, London, 1994
6. ISO 9080, *Plastics piping and ducting systems – Determination of the long-term hydrostatic strength of thermoplastic materials in pipe from by extrapolation*
7. ISO 1043-1, *Plastics – Symbols and abbreviated terms – Part 1: Basic polymers and their special characteristics*
8. ISO 15874, *Plastics piping systems for hot and cold water installations – Polypropylene (PP)*
9. ISO 13760, *Plastics pipes for the conveyance of fluids under pressure – Miner's rule – Calculation method for cumulative damage*

10 E DIN 8077, *Polypropylene (PP) pipes – Dimensions*

11. DIN 1988, *Codes of practice for drinking water installations (TRWI)*
12. Guideline DVS 2207-11, *Welding of thermoplastics – heated tool welding of pipes, pipeline components and sheets out of PP*
13. SKZ HR3.34, *Pressure Pipe System made of PP-RCT*
14. E DIN 8078, *Polypropylene (PP) pipes – General quality requirements and testing*
15. ÖNORM B5174, *Pipes of polypropylene – Dimensions, requirements, tests, marking of conformity*